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FIFTH ANNUAL REPORT

OF

The Department of Public Works and Buildings

Division of Waterways

July 1, 1921

TO

June 30, 1922

AUG. 26TH 1818

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R. MILLER, Director
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Superintendent, Division of Waterways

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DIVISION OF WATERWAYS.

William L. Sackett, *Superintendent.*

FLOODS IN ILLINOIS—1922.

Damage by floods in Illinois in March and April of 1922 was so serious and widespread as to prompt investigation by the Division of Waterways as to the cause, result and method of prevention in future.

Engineers were sent to all points of the State during the height of the flood to note and to record conditions. While there was no loss of life to add to the property damage, estimated to approximate five millions of dollars, conditions at Beardstown, Naples, Peoria and other points along the Illinois River were such as to create much apprehension for several days for the safety of hundreds of people, many of whom were compelled to abandon their homes.

A continuous and heavy rainfall of several days resulted in such rapid run-off from drainage areas that rivers were incapable of carrying it in natural channels. Levees along the Illinois River at several points were carried out, inundating large reclaimed areas that previously had provided storage basins for water in flood periods.

Beardstown suffered the greatest damage of any municipality yet escaped serious results anticipated. Published reports of a declaration of a citizen of that city that the Sanitary District of Chicago was entirely responsible for the flood and damage because of diversion of water from Lake Michigan for sanitary purposes presented such a serious charge that it seemed necessary facts be ascertained.

This division, a State agency with no interest other than serving all people of the State, began its investigation before the crest of the flood was reached, and found that while diversion of water from Lake Michigan by the Sanitary District of Chicago was a contributing factor, construction of levees along the Illinois River for reclamation of land, had so narrowed the natural flood plain of that river that flood heights were materially raised. This was especially true of conditions immediately below Beardstown, created by construction of levees that reduced the discharge width of the river to approximately 1,200 feet. This is, and will prove true of other streams if continued in the future as in the past. This work has been done without supervision by any Federal or State agency. Present State statutes give the Division of Waterways some control, and it is possible review of plans in future may curtail, to some degree, additional flood damage by preventing future unreasonable encroachments upon natural flood plains of streams. This will interfere with reclamation of some land but there will be less loss in this than will result in life and property loss in populous communities along rivers of the State.

Summarized, the following conditions were found responsible for the floods and resulting damage in the Illinois Valley:

1. The construction of levees along the Illinois River which restricted the discharge capacity of the stream and eliminated natural reservoirs.

2. Reclamation of land and drainage into tributary streams permitting greater quantities of water to reach the river in a given period of time.

3. Straightening and draining of the Kankakee River in Indiana.

4. Addition of approximately 8,000 cubic feet per second of water by diversion of water from Lake Michigan.

5. Silt brought to the Illinois River and valley from tributary streams due to higher velocities created by river improvement. From the investigations made by the Division of Waterways a flood as great as that in 1922 must be looked for approximately once in ten years and greater floods may be expected at longer intervals and higher flood elevations may be looked for in the future as additional lands are reclaimed and greater restriction is placed on the discharge capacity of streams if flood plains of the streams are encroached upon as seriously in the future as they have been in the past.

The investigation of flood conditions of 1922 for the Division of Waterways was made by Mr. M. G. Barnes, Chief Engineer. His report is as follows:

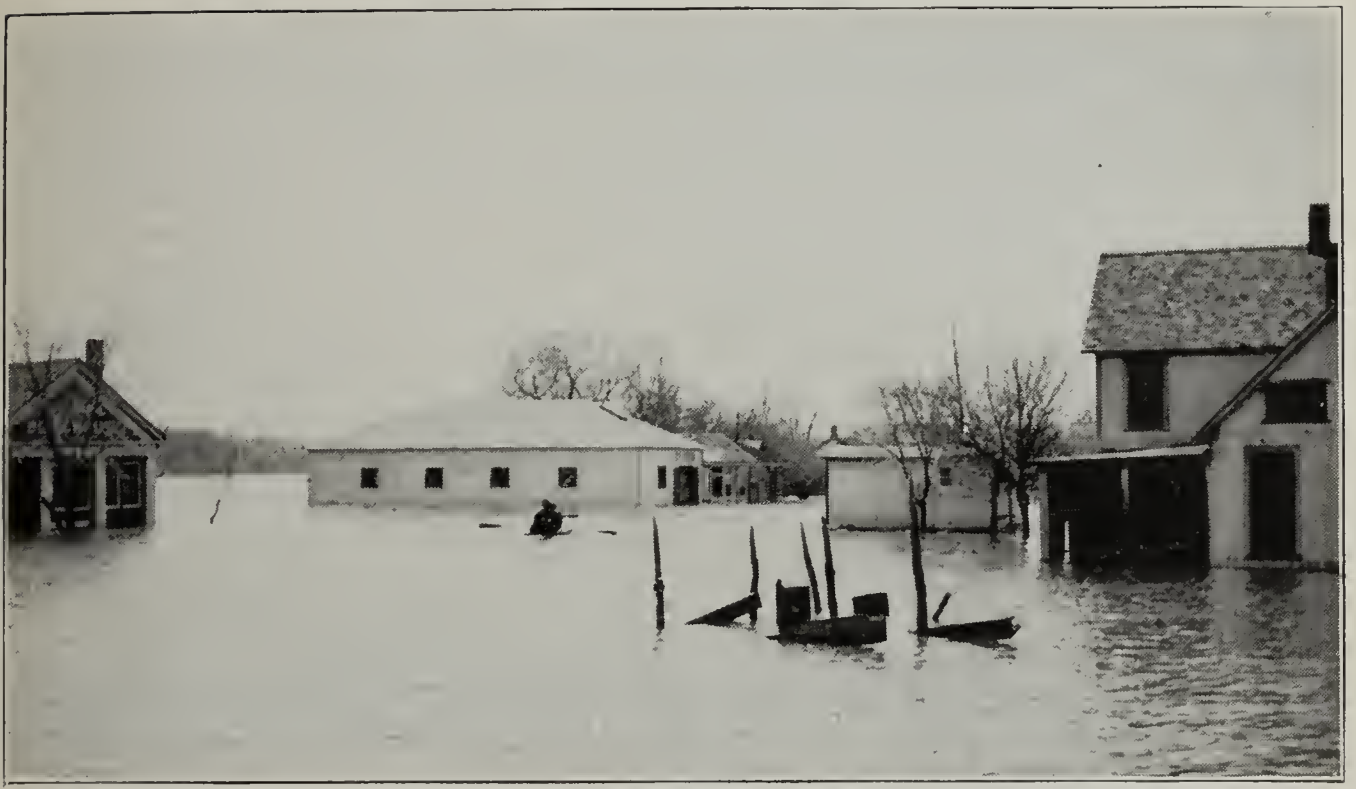
REPORT OF M. G. BARNES, CHIEF ENGINEER.

In 1914, the former Rivers and Lakes Commission employed Alvord and Burdick, a Chicago firm of engineers, to study this troublesome problem and report their findings to the commission. After an exhaustive survey and study of all the conditions, they reported back to the commission, and, in 1915, their report was published as a State document under the title of "Report of the Rivers and Lakes Commission on the Illinois River and its Bottom Lands." A second edition of this report was published in 1919 by the Division of Waterways, successor to the Rivers and Lakes Commission. The recommendations made by these engineers have been public for about seven years, but have remained unheeded.

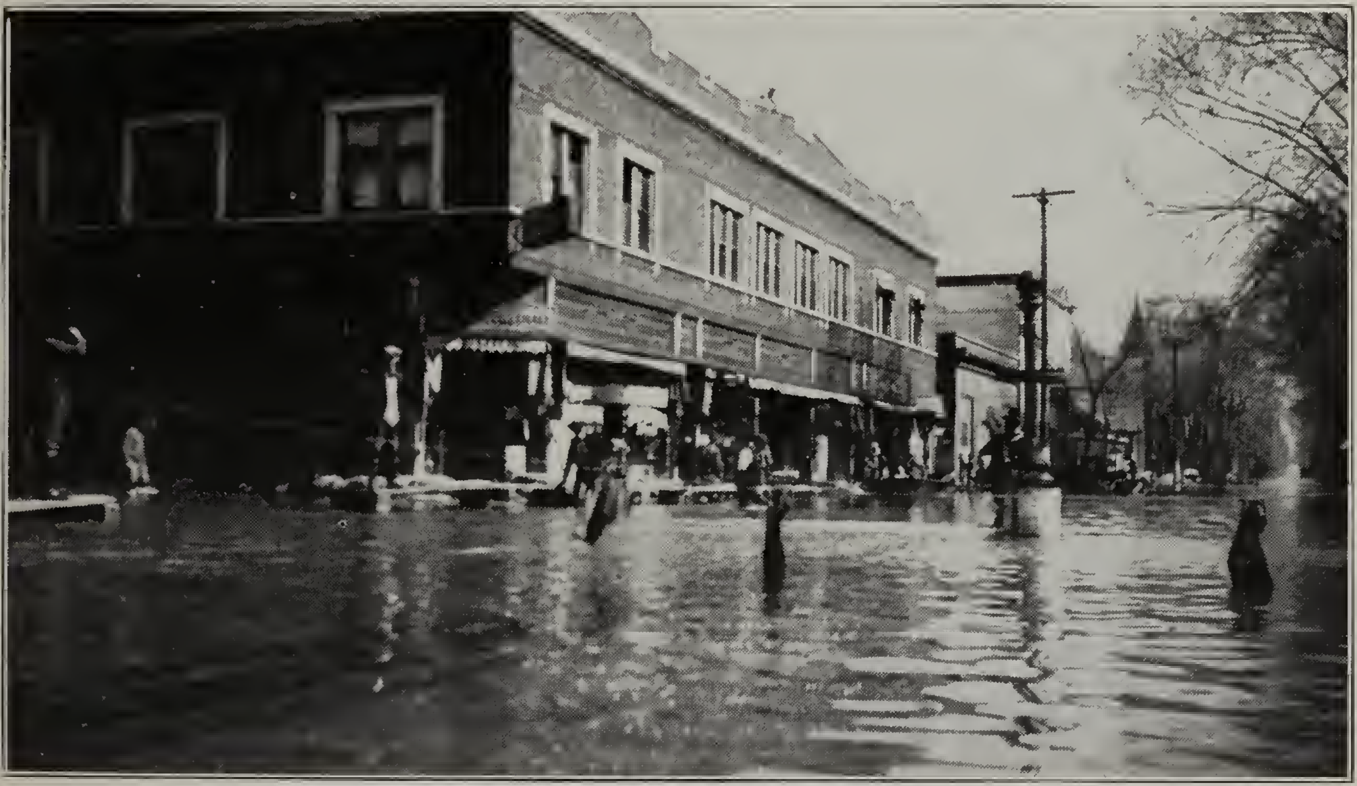
The writer of this report can add but little to what those engineers said at that time. He will attempt to review that part of the report dealing with floods and their causes and deal with a technical problem in the language of the layman. If he succeeds in demonstrating to the people of the valley the flood dangers that confront them, his work will not be in vain.

It requires a catastrophe such as visited the Illinois Valley this year to rouse a community from its slumbering senses and spur it to action. These floods are of frequent occurrence, at least three of similar magnitude having visited the Illinois River in the past two decades.

Not always are these visitations of excessive rainfall confined to a community nor are they general in their scope. One year we will read of great floods along the Hudson and Mohawk Rivers and the people of Albany, Troy and other low-lying districts will be inundated and crying for relief. Another year floods occur along the Miami River and untold millions of damage occur at Dayton and other districts along its course. Last year the Arkansas was in flood and the property damage at Pueblo exceeded nineteen million dollars and probably 100 people lost their lives. On the Ohio and Mississippi, the recurrence of these floods are so frequent as to become almost commonplace.



Frederick. Taken from C. B. & Q. track.



Beardstown, Illinois. High water of 1922 (crest was 6 inches higher than picture).

In each of the instances cited, the great destruction of life and property has been very largely the direct result of the act of man by his encroachments and other violations of the laws of nature. If one will read the history of the various communities where great devastation has taken place and study the causes and effects he will readily see that the unusual flood heights were a direct result of encroachments and that life and property could have been saved by proper regulations of the stream and this at less cost than the damage done during one flood. The early settlers at the present site of Dayton, Ohio, observed that a levee two or three feet high would protect their property from the greatest floods that had ever visited that valley. Levees were thrown up a few inches above the highest flood of record only to be overtopped at the next high water. Levees were again built a few feet higher, to be sure to be above the highest flood stage of record. Again these were overtopped and the rebuilding at increasing heights continued until the great devastation of 1913. After that great flood, the people of Dayton and vicinity employed a firm of engineers to tell them what to do to secure relief from a recurrence of floods similar to the one they had just passed through. As a result of their studies, a system of restraining reservoirs was provided, bridges were rebuilt with greater length and fewer piers, channels were cleaned out, deepened and straightened, buildings, levees and other encroachments were pushed back from the banks of the river and Dayton's flood problems were solved for all time.

When the early pioneers settled on the Mississippi River, they found it possible to protect themselves with a levee some three feet in height. This was accomplished at extremely low cost. As settlement increased and ever increasing areas were protected, it was found that the levees must be made progressively higher. Each recurring flood overtopped them and their heights were increased until now many of them exceed thirty feet. Formerly the river overflowed to a depth of a few feet and spread out over an area of 20 to 100 miles in width along the lower valley creating immense temporary reservoirs that prevented the river from reaching great heights. Many of these reservoirs have now been cut off by the levees and although the flood discharges of the river do not greatly exceed those of former days, the river must reach much higher stages in order to discharge its waters.

The history of the Miami and Mississippi Valleys is no different than the history of the Illinois Valley except possibly in the latter case collateral factors have contributed to increase flood heights. In 1916, Mr. L. K. Sherman, chief engineer of the Rivers and Lakes Commission, said that since 1908 the levee districts along the Illinois River have reduced the flood plain or area of land covered by flood waters 40 per cent, equal to 172,000 acres. This encroachment has continued until now over 200,000 acres have been reclaimed out of the original flood plain, thus reducing the reservoir capacity of the stream.

CONTRIBUTING FLOOD CAUSES.

Let me review briefly what has taken place elsewhere in the State which adds to the flood discharges of the Illinois River. The State Geological Survey estimates, in Bulletin No. 42, that "drainage, levee and sanitary districts to the number of 1,043 have been formed up to the present time. The 4,608,880 acres contained in these districts constitute 12.6 per cent of the area of the State. About 4.3 per cent of the area within districts needs further attention." The effect of draining this land can be best understood by a homely illustration which will be readily appreciated by readers having had farm experience. During each winter season the barn yards are covered with a deposit of straw, corn stalks, manure, and other debris, which become thoroughly saturated in the spring. The first duty of Mr. Farmer after a heavy spring rain is to take his fork and rake and make channels through this accumulation so as to drain his barn yard into the brook below. The drainage districts along the head waters of the streams are the farmers' barnyards on a large scale. Marshes and flood lands prevail generally at the stream's source. In nature these are great reservoirs where water is held back by rank vegetable growth. When settlement takes place large open ditches are cut through these flood lands which more or less efficiently drain off the water. These ditches are supplemented by a net work of tiles which quickly discharge the ground water to a depth of three to five feet below the land surface. This reclamation has continued in Illinois until now there are upwards of 750 million feet (142,045 miles) of tile in the State draining into open ditches. The effect of these ditches and the supplemental tiling is the same as the farmers' barn yard ditches and were installed for the same purpose, i. e., to more quickly discharge surplus waters. The second effect has been to increase the high water stages on the unimproved streams below the outlet of these ditches. Lands bordering these streams must be protected and drained in self defense which in turn adds to the trouble of those yet further down stream. The next stage in land reclamation is to cut new channels for the trunk streams greatly increasing their discharge capacity both by increasing the depth and cross section of the stream and shortening its length by cutting off the numerous bends in the natural stream. Many argue (and under certain conditions properly) that the drainage above cited lessens the flood height rather than increases it. With normal rainfall and under certain conditions these arguments are sound but it is not with normal rainfall that we are concerned. It is only the abnormal conditions or the storms that occur say once in a decade that cause damage. The abnormal conditions may be—

A. Heavy downpour occurring after a long period of wet weather which has thoroughly saturated the ground and filled tiles and drainage ditches, or

B. Heavy downpour falling on frozen ground covered by a heavy blanket of snow.

In each of these conditions, the drainage ditches and tiles aid in discharging the surplus waters which must of necessity accumulate and cause higher water in the valleys.

In many instances, the discharge capacity of the new channels is made twice the capacity of the stream in its natural form and the distance between tributaries has been shortened at least one-third with the result that three times the amount of water may reach the lower sections of the stream in the same period of time that it formerly required. A very good example of such improvement is found on the Kankakee River. This stream has been improved for a distance of approximately 70 miles from the State line back into Indiana, and, whereas originally the stream was flat, winding, and shallow, now it is straight and deep with fully twice its original discharge capacity. The adjacent lands have been drained into this new channel by open ditches and tiling so as to afford relatively free run-off from lands that were formerly largely lakes and swamps.

NATURAL CONDITIONS CHANGED.

The natural discharge of the Illinois River is changed to a marked degree by water brought to it from an outside source through the Chicago Sanitary Canal. The influence on the low water stage is most marked. Previous to the opening of the Sanitary Canal on January 17, 1900, the low water discharge of the Illinois River at Peoria commonly fell below 2,000 second-feet. The Sanitary Canal now adds more than four times the natural low water discharge of the Illinois River at Peoria. The low gage height has been raised five feet at that point. The effect decreases from Peoria to Grafton at which latter point it is inappreciable.

Probably the most damaging effect of the sanitary water occurs at the low water season. During this low water period thousands of acres of land are inundated, much of which was tilled previous to 1900. Other portions supported a heavy growth of timber which has been killed by permanent flooding and stands as a ghastly reminder of the blighting influence of this additional water during the growing period. Another result of this added water has been to hasten the construction of levee districts which in turn increase the high water stages. As much of this reclaimed land cannot be drained now, even at low water periods, pumping must be resorted to which

East Peoria District. Showing top of levee raised by sand bags. This district was saved.

Beardstown, Illinois. Water rose about seven inches higher at crest.

is seriously resented by the drainage commissioners. The effect of the Sanitary Canal water on the flood stages is not so marked. The influence at such stages will be mentioned later.

There is a group of other causes which affect the high and low water stages of the streams in the Illinois Valley. Each of these causes in itself has only a minor effect and in some instances is not noticeable but under certain conditions may become contributing factors in causing flood damages. In this group may be mentioned such obstructions as dams, piers, breakwaters, artificial fills on shore and in the channel, felling trees into the water, buildings within the flood plain, bridges and numerous other obstructions. Fallen trees often result in the formation of islands by the collection of debris and silt on which willows soon find a foothold. This increases in size from year to year by constant adding of debris and silt until an island is formed that often causes a serious ice gorge. Too often bridges are constructed with short spans and numerous piers within the flood plain. The bridge itself is often only a few inches above the flood stages. Such conditions are favorable to the collection of all manner of floating objects gorging the stream to unusual heights and frequently causing the failure of the structure itself. The excuse or reason for such structures is cheapness of construction and economy in maintenance. These are worthy objects in themselves, but here, as in many other cases, one cannot get something for nothing. This is an economic question. Cost must be balanced against probable damages and a proper solution found. The designer should always bear in mind that the damage is usually to individuals while the saving in cost is public.

The above is a recital of the acts of man that affect run-off and river stages. Consider now briefly the natural elements affecting these conditions.

DRAINS LARGE AREA OF STATE.

The Illinois River drains about 40 per cent of the land area of the State. Its slopes are unusually flat especially in the northeastern part of the State. Hence the necessity of drainage. In the first fifty miles of the river below the junction of the Kankakee and DesPlaines Rivers the slope is a little more than one foot per mile. In the next 80 miles the slope or fall is only 6 feet. The lower 153 miles has a fall of 27 feet. Because of this flat slope the stream does not discharge its waters rapidly. Below LaSalle the valley is from 1½ to 7 miles wide. In nature about 400,000 acres of this land was subject to overflow. The banks and low lands are in most part covered with a rank growth of trees, shrubs and vines which present almost an impassable barrier to the discharge of water outside the river channel.

Many small lakes are found along the valley through which part of the water flows at flood periods.

The mean annual rainfall in the north end of the State is 34.3 inches. In the central portion 37.5 inches and in the south end 42.5 inches. The south half of the State lies in the path of the great cyclonic storms which pass over the country annually. Plate 1 shows the precipitation for April, 1922, and is typical of these storms. They strike the gulf coast near Galveston, proceed in a northerly direction to the southern line of Missouri, thence take a northeasterly course to the St. Lawrence River. It will be seen, therefore, that the southern half of the State is much more subject to heavy precipitation and floods than is the northern half.

Having reviewed the flood causes both natural and artificial, let us now consider the effects. The greater portion of the State drained by the Illinois River is covered with a thick glacial deposit and the slopes being flat it absorbs the precipitation readily and gives it off reluctantly. Hence we have a stream in nature of relatively light floods and discharging a small per cent of the annual rainfall. This fact taken with the large natural reservoirs of the Illinois and its tributaries prevented any very high waters as long as the stream remained in the state of nature. After the heavy spring rains had ceased the run-off became very light and the river so low that the bottom lands could be tilled and cropped with but very little loss from floods. As the land along the tributaries was drained, greater amounts of water were brought to the river and silt deposit increased thereby, choking the river and adding to the heights of the low shore lines and islands. This condition was greatly aggravated by the addition of water brought to the river from Lake Michigan through the Chicago Sanitary Canal. As settlement increased and land became more valuable, levee districts were organized to reclaim this low land and the natural lake beds for agricultural purposes. These districts have already reclaimed more than half of the low lands formerly forming part of the natural reservoir system. The volume thus eliminated from storage is sufficient to take the entire flood discharge of the river for a period of five days. In many instances the flood plain has been reduced by these levees at least 80 per cent and in some cases it is restricted to a narrow gorge 1,200 feet to 1,500 feet wide. The effect of these levees is best understood by reference to Plate 2 on which are typical cross sections of the valley after being leveed. These show portions of the valley three miles in width narrowed to a width of 1,200 to 1,500 feet. All outside the levees was formerly available as reservoirs and as a passageway for the water. It requires no technical discussion to demonstrate that to discharge a given amount of water the river must be deeper and therefore "higher" after the levees are constructed than before. It has been estimated that in general the great floods prior to extensive levee construction travelled 40 to 50 per cent over the low lands and 50 to 60 per cent by the channel proper.

The effect of levees is shown on Plate 3. On this plate have been drawn the high water profiles of four floods. Those of 1844, 1904, 1913 and 1922.

The evidence indicates that all these floods were of substantially the same volume at Beardstown. At Peoria the 1844 flood was 15 per cent greater than the 1904 flood and the 1913 flood 10 per cent less than the 1904. These are the conclusions of Alvord and Burdick in their report above referred to.

HOW LEVEES CHANGE FLOOD HEIGHTS.

The profiles of these floods show the effect levees have on flood heights. The influence upon the stage of the Mississippi River is felt in the Illinois River back for a distance of from fifty to one hundred and fifty miles, depending upon the relative stages of the rivers. The greatest amount of land reclamation has taken place within a distance of 50 miles either side of Beardstown. Reference to Plate 3 will show that as this reclamation work has proceeded floods have progressively assumed steeper slopes in the vicinity of Beardstown. The 1922 flood, while of approximately the same volume as the 1904, was five feet higher at Beardstown. The elevation of the floods of 1904, 1913 and 1922 approach each other as we progress upstream. At Henry the difference between elevation of the highest and lowest of these floods is only about 15 inches. Alvord and Burdick computed what the elevation of the 1904 flood would have been had all the levees on the Illinois River been completed. This profile is shown as profile "G" on this plate. Note how nearly this profile corresponds with the 1922 flood above Pearl. The 1922 flood occurred at a time when the water was not excessively high in the Mississippi River at Grafton. Had this flood occurred with the river at Grafton at the same elevation that it was at the time of the 1844 flood, i. e., six feet higher, the elevation at Beardstown would have been nearly two feet higher.

The excessive storms that caused the floods of 1904, 1913 and 1922 passed over only the southeastern portion of the catchment area of the Illinois River. Had these storms been generally heavy throughout the State these floods would have reached much greater heights. These three floods occurring nine years apart are running true to form and are what may be expected about once in a decade. We may expect that these floods will be 20 per cent greater about once in 25 years and 30 per cent greater once in 50 years. Both these periods have been over extended and such storms may be expected at any time. Alvord and Burdick assumed that the 1904 condition may be exceeded 35 per cent about once in 50 years and that it might occur

South Beardstown District showing work to save levee.

Chatauqua Drainage District Pumping Station. Remnants of levee.

with the water in the Mississippi River at the 1844 elevation. They computed the height that such a flood would reach along the lower Illinois River with the river fully leveed. Their computed profile is shown as "H" on Plate 3. This does not represent the highest flood that may occur, but greater floods are of less frequency. Once in 100 years to 300 years, these floods may be greatly exceeded.

EFFECT ON WATER LEVELS AT FLOOD STAGES.

All the freshets that have occurred since January, 1900, have been increased by water brought to the valley from Lake Michigan through the Chicago Sanitary Canal. The amount that this foreign water has increased the gage heights at points along the river can be determined by an examination of Plate 4, which shows the rating curves at three points along the river—Peoria, Havana and Beardstown. At each of these stations are shown the rating curves established in 1904 by the United States Engineer Office and in 1922 by the United States Geological Survey. These curves show graphically the effect levees have had on gage heights. The curves established in 1904 curve sharply down to the right after the river has broken out of its channel banks. Above this point it requires much more water to increase the height of the river a given amount. These curves flatten from Peoria down stream owing to the wider valley at the lower points which in turn require a greater flow to increase the flood heights. The 1922 curves curved downward to the right after the river had broken out of its banks, but not so steeply as the 1904 curves. This is because of a lesser reservoir capacity and therefore requires less water than formerly to raise the stage a given amount. Having plotted these curves one can read from them the difference in gage height corresponding to a given discharge. The amount of water discharged from the Sanitary Canal during flood periods averaged approximately 8,000 cubic feet per second. Applying this quantity to the top of the 1922 rating curve at Peoria, it will be seen that the Sanitary Canal water increased the flood height 18 inches. Had the levees not been constructed this same quantity applied to the top of the 1904 curve would have increased the gauge height only 12 inches. At Havana the increases in gauge height are 12 inches and 7 inches respectively; at Beardstown 6 inches and 4 inches respectively. The influence of the Sanitary Canal is felt a lesser amount at Beardstown than at Peoria. At Beardstown the sanitary water amounted to about 7 per cent of the total flow of the stream whereas at Peoria it was about 14 per cent. The influence of the water from the Sanitary Canal can be read from these curves at any stage in the river. For example, the amount that 8,000 feet of water from the Sanitary Canal will raise the gage heights at low water flow is shown to be—

At Peoria	5.4 feet
At Havana	2.8 feet
At Beardstown	2.2 feet on 1922 curve.

It must be admitted that these rating curves are subject to errors and inaccuracies which may be either plus or minus, but in the absence of any other information they must be taken as the best evidence available.

EARLIER ENGINEERING RECOMMENDATIONS.

Plate 5 shows in full line the profile of the 1922 flood and the influence that the levees and the water from the Sanitary Canal have had on the flood stages. The upper broken line shows the height the water would have attained had there been no water from the sanitary canal. The middle broken line shows the elevation that would have obtained without the levees but with the Sanitary Canal water. The lower broken line shows the elevation that would have obtained in nature.

We have now considered the causes, both natural and artificial, of floods and the effects. Let us now discuss remedies. In discussion of this phase of the subject, Alvord and Burdick make the following statements:

"It is doubtful if anyone will seriously consider the abandonment of the investments in the valley and the reverting to conditions of nature which would be likely to correct the present difficulties. For obvious reasons it is out of the question that we go back to the days of the buffalo and the Indian.

"Referring particularly to the flood situation, the remedies are of two classes, first, channel improvements, and second, storage.

"Channel improvements will include all means of providing a more adequate waterway for the passage of the floods. This may be accomplished in a number of ways as follows:

"(a) Through increasing the height of the agricultural levees, thereby permitting the flood waters to occupy a greater cross-section without flooding the farm lands.

"(b) Through lowering the bed of the channel, perhaps through cooperation with one of the several plans for a deep waterway.

"(c) Through greater widths between levees where same are built on both sides of the stream or elsewhere by setting the levees back at greater distances from the river. This is hardly a practicable remedy where the levees have been built. It is easily applicable, however, to future levee construction.

"Storage if properly applied, will be efficacious in reducing the rate of flow at critical periods in a flood, and hence it would have a tendency to reduce maximum flood heights. Storage may be beneficially applied to the Illinois River in two ways:

"(a) Through storage in the Illinois River bottoms, and

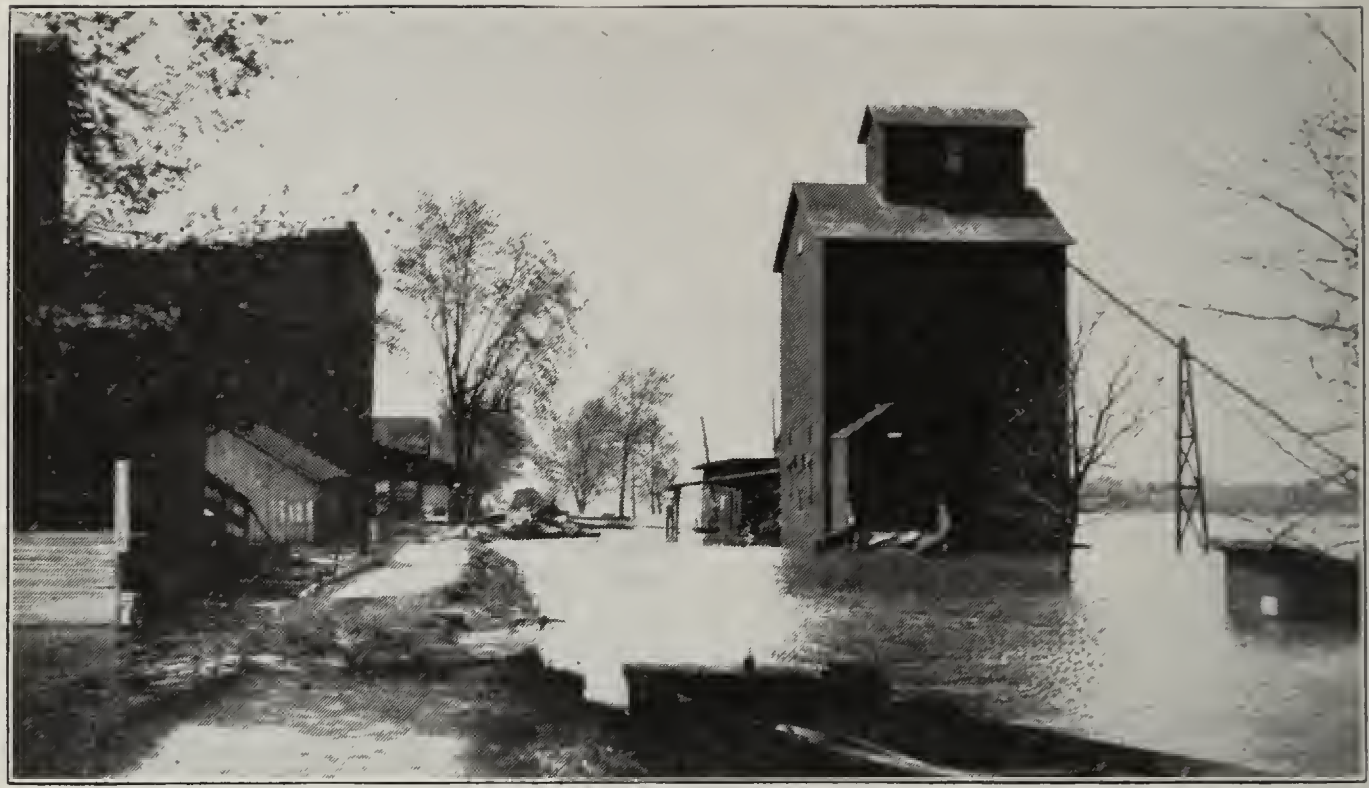
"(b) Through storage in the valleys of the tributaries."

There might be added to the recommendations of these engineers, the removal of trees from the area between the levees. These trees have a serious retarding effect on the water passing through the area occupied by them. The drainage commissioners object to the removal of these trees because they present very efficient protection to their levees from wave action. These levees could be protected by stone rip-rap, but of course at great cost. Numerous islands are found along the river covered with heavy growth of trees and underbrush. Those also seriously retard the flow of water. These islands might be removed where levees have been constructed with marked benefit to the discharge of flood waters. Even close pasturing of the islands and timbered shore lines would aid in discharging floods.

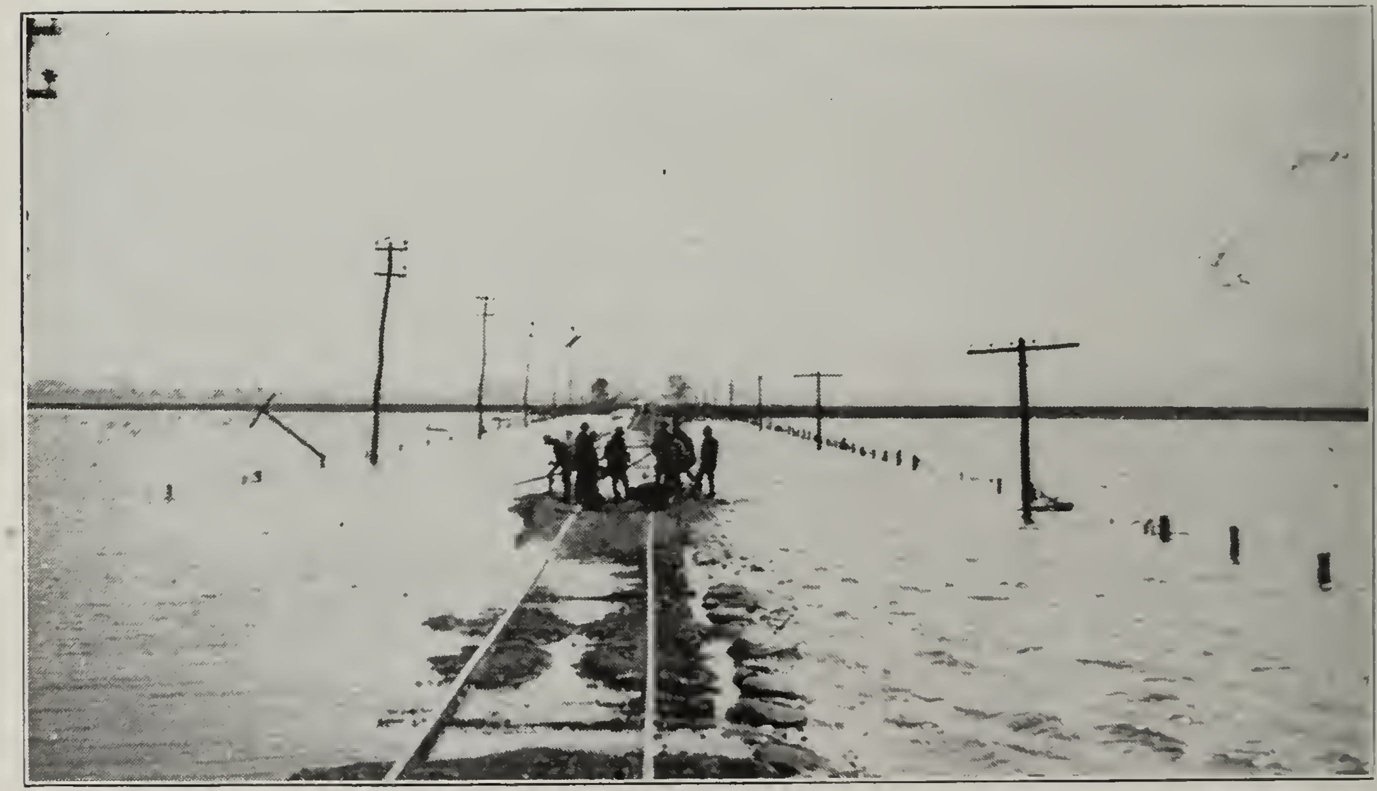
STORAGE RESERVOIRS BEST REMEDY.

The creation of storage reservoirs to control flood heights is the most efficacious means available. However, the proper application of this remedy under the conditions obtaining along the Illinois River is not so simple. To get the greatest benefit from storage reservoirs along the Illinois River, they must be kept empty until the flood approaches the danger line. Some centralized power must then have authority to open gates and flood successive reservoirs sufficiently to keep the flood stage below the danger line. If enough of these drainage districts now organized and in operation and those yet to be organized are used for this purpose, the flood height can be materially reduced. The use of these drainage districts for reservoirs does not mean that they should be abandoned for agricultural purposes. Floods similar to the one that occurred this year do not usually recur oftener than once in ten years. In the ordinary freshet these reservoirs would not be required and the lands could be used for agricultural purposes without damage. The occasional flooding would add to the value of the land by the fertilizer brought to it and at least partially offset damage resulting from an occasional flooding. If such a procedure were to be followed, it would be necessary of course to limit the amount of building and number of inhabitants on flooded areas so that they could be safely removed in times of necessity.

Plate 6 shows the elevation of the Illinois River at various points during the flood of March and April, 1922. On this plate has been shown with a cross (x) the points at which the various levees broke and the effect in the



Naples, Illinois. Illinois River on right. River levee in foreground.



Wabash R. R., east of Naples. All flooded farm land. Taken from rear of train.

flood profile of the filling of the reservoirs thus made available. This condition was most marked at Beardstown on April 16 when the flood nearly reached its maximum stage. On that date the levees at that locality failed and the water at Beardstown receded some three or four inches, whereas, at Havana and Pearl on either side of Beardstown, the water continued to rise. The water at Beardstown remained stationary until the reservoirs were filled when it again began to rise and continued so to do until another levee broke. Before this reservoir was filled, the flood began to subside. The breaking of these levees and the filling of the reservoirs back of them indicate the value of reservoirs as regulators of flood stages.

If storage is not resorted to, the levees must be increased in height or the damage that will certainly occur, probably once in a decade must be accepted. As the number of levee districts is increased, the levees must be increased in height for self protection. The raising of these levees will not of course protect such localities as lower Peoria and Beardstown, which latter place suffered seriously in the flood of 1922. Alvord and Burdick computed the height they found necessary to protect the land from floods 35 per cent greater than the 1904 flood without storage. The height of the levees recommended by these engineers is shown by "L", Plate 3. If storage is provided they recommend that the levees be built to elevation shown by line "K."

The improvements of the river for navigation purposes will have a slight influence only on the flood stages. Its greatest affect will be on lowering the low water stages. Plate 7 shows the low water stage with an increment of 4,167 cubic feet per second and 8,500 cubic feet per second from Lake Michigan respectively each with existing dams in place. Also the low water profile with increment of 8,500 cubic feet per second from Lake Michigan, but with all dams removed and the channel deepened to a depth of 9 feet throughout. This latter is the improvement recommended by the Division of Waterways for navigation purposes.

Property damages suffered by the 1922 flood probably exceeded two million dollars. If this sum had been spent on remedial works, it would have gone far towards improvement of channel conditions and protection of property. The United States Engineers Office made a survey and estimate of damage done by the 1922 flood. Copy of Major Putnam's report follows. It is believed that his estimate is conservative.

REPORT OF U. S. ENGINEER.

JWW-K
April 29, 1922.

"From The Acting District Engineer,
" to The Chief of Engineers, U. S. Army, Washington, D. C.
"Subject Illinois River Flood of April, 1922.

"1. Supplementing my report of April 18, 1922, which was confined to flood conditions at Beardstown and immediate vicinity, the following information is submitted in regard to the character and effect of the flood from Peoria to the mouth, based on an inspection made by boat by Assistant Engineer Fuller:

"2. The flood now passing is the highest on record between Havana, mile 120, and Valley City, Mile 61. Elsewhere it is the highest on record since 1844, except at LaSalle, where it was exceeded in 1916. The following table gives comparative gauge readings at the principal points between Peoria and the mouth for four of the largest floods which have occurred on the Illinois River.

MAXIMUM GAUGE READINGS DURING FOUR FLOODS.

	1844	1904	1916	1922	Date of maximum.
Peoria	26.3	23.0	23.1	24.7	April 17.
Havana	22.0	19.9	19.5	22.5	April 18.
Beardstown	22.5	20.0	20.6	25.1	April 20.
Pearl	26.5	19.4	19.8	23.0	April 19.
Grafton	32.3	19.9	23.4	25.8	April 20.

"3. On April 1st there were known to be 47 drainage and levee districts along the Illinois River between Peoria and the mouth, inclosing approximately 220,000 acres, which had their levees practically completed. A very few of these had not installed pumping plants, but most of them had been in cultivation for a number of years, some of them previous to the survey of 1902-1904. The levees inclosing 17 of these districts were broken during the present flood, rendering many people homeless, destroying much of last year's crops and preventing the raising of any during the present season. A list of the districts which have been flooded by the breaking of levees, giving the acreage and estimated amount of damage for each is submitted below:

"4.

Miles from Grafton.	Name.	County.	Acres.	Damages.
33	Fairbanks	Greene	9,000	$265,000
39	Hartwell	Greene	9,500	285,000
57	Scott County	Scott	10,000	365,000
*62	Anderson Lake	Pike	5,000	10,000
58	Oakes	Scott	400	10,000
59	Mauvaiseterre	Scott	1,800	40,000
73	Meredosia Lake	Morgan-Cass	4,300	110,000
*77	Kerr & Crane	Brown	800	8,000
78	Kerr	Brown	400	13,000
84	Crane Creek	Schuyler	5,100	150,000
85	Coal Creek	Schuyler	7,400	300,000
89	Lost Creek	Cass	3,000	45,000
98	Kelly's Lake	Schuyler	3,000	35,000
*120	Thompson Lake	Fulton	7,000	10,000
*121	Chautauqua	Mason	5,000	8,000
*128	Liverpool	Fulton	4,500	7,000
151	Lamarsh	Peoria	3,000	130,000
88	City of Beardstown (Not protected by levee)		800	200,000
65	Village of Naples (Protected by a levee, but had no pumping plant)		500	25,000
			77,500	$2,016 000

* Levees not completed to full height.

In addition to the above, more or less damage was done by the flood at Peoria, Pekin, Liverpool, Havana, Bath, Browning, Frederick, Valley City, Florence, Montezuma, Bedford, Kampsville and Hardin; but no attempt has been made to estimate it. There is but one district above Peoria, the Hennepin, of 2,500 acres, so that section of the river has not been covered.

"5. The inhabitants seem to be worse off at Naples, Mile 65, than at any other locality. The town is entirely submerged, except a small knoll situated on the river bank. About 400 people are living in tents and a few houses on this knoll. The Red Cross is supplying them with provisions. The majority of the inhabitants live by day labor and have now no opportunity to earn a living. The United States Coast Guard has four motor boats at Naples assisting in the relief work. The steamer Illinois, owned by the State of Illinois, is also assisting in the relief work at various points along the river.

"6. Since the dates of the maximum gauge readings, given in the table above, the river has been falling steadily, at first one to two-tenths a day, and at the present time three to four-tenths of a foot per day.

Carmi, Illinois. From highway bridge.

Naples, Illinois. Street scene. Water 6 to 10 feet deep in streets.

"7. The flood this year has shown that most of the levees on the Illinois River are neither high enough nor strong enough to withstand such a flood as has prevailed during the month of April, with any degree of safety. In the districts that were not flooded large forces of men were employed day and night for two or three weeks strengthening and raising the levees in order to prevent ultimate failure. The conditions in nearly all of the districts became so dangerous that nearly all of the inhabitants moved out from the valley temporarily.

RUFUS W. PUTNAM,
Major, Corps of Engineers.

"P. S.—Some estimates of the amount of damage caused by the flood are much larger than the total given in paragraph 4. One firm of Civil Engineers at Beardstown places the total at $20,000,000.

REPORT ON FLOOD DAMAGE.

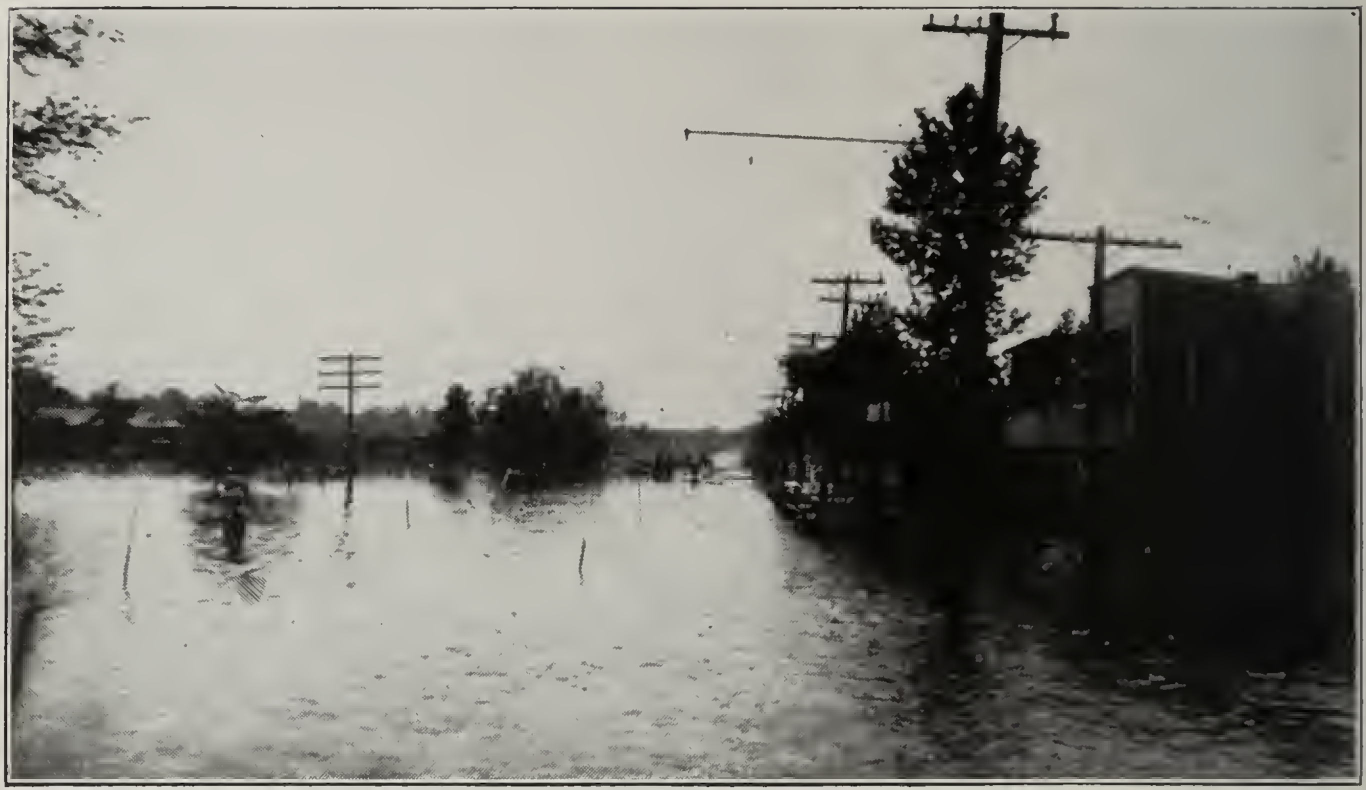
A more detailed report of the damage done by this flood but without assessing the money value was made by the U. S. Department of Agriculture, and will be found in Climatological Data for April, 1922, published at Springfield by direction of H. Merrill Wills, Meteorologist. Excerpts from this report are quoted below:

"For the State as a whole, the rainfall in March was the heaviest on record for that month, with one exception, and was twice the normal fall. Most of the month's rain fell during approximately the last half, being especially heavy on the 14th and moderately heavy on the 19th; and beginning on the 24th it rained on almost every day until the close of the month, then kept up quite generally until April 17th, during which period 17 inches of rain fell in parts of central Illinois; and all previous April records were exceeded at three other points. There was little evaporation, and the soil was found to be heavily saturated by the end of March. There was a gradual rise in the streams and nearly all the larger ones of the central and southern divisions had gone into flood by the close of the month, inundating many lowlands, and this condition increased with the continued rains of April. The Illinois River between Peoria and its mouth was closely approaching record stage by April 10th and levees began to give way, or were overflowed, at many points, flooding thousands of acres of rich bottom lands along the river and its tributaries. Similar condition obtained also on the Mississippi River between Chester and Cairo, and the Wabash-Ohio Rivers bordering southeastern Illinois. Although the saturated condition of the soil resulted in a rapid run-off, this seems to have been but a minor contributing factor in the Illinois River flood, the unprecedented stage being accounted for, mainly, as follows: The water that was poured into the alluvial river (the Illinois below Utica) by the up-river and the tributaries, caused a rise in the alluvial stream. Ordinarily the discharge of such increased amounts of water is slow on account of the flatness of the grade, but this year it was particularly slow on account of the high Mississippi, which lessened the natural slope and thus held back the waters of the Illinois. Before the waters from one storm could be discharged, other rainstorms came and were poured into the alluvial stream, swelling its slow-moving contents to unprecedented heights.

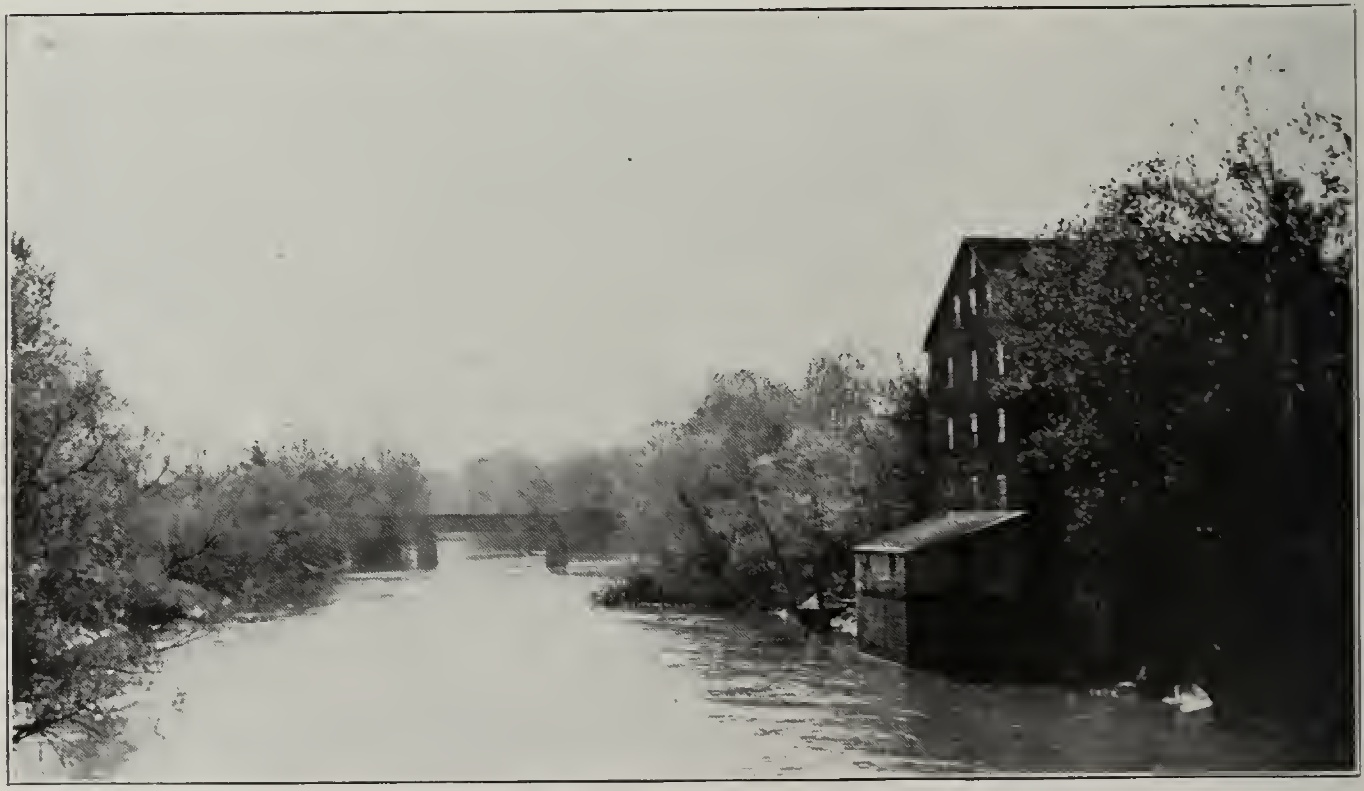
"Upon the basis of all dependable information that has been obtainable up to the time of this writing, a summary of the total acreage inundated in the three main devastated areas, shows the following estimates: Illinois River Valley below Peoria, 175,000 acres; Mississippi River counties below Chester, 125,000 acres; Wabash-Ohio River counties, 100,000 acres; grand total for the State, 400,000 acres. These are believed to be very conservative estimates, and the final figures may far exceed them. A large proportion of the flooded areas was in growing crops, mainly winter wheat, with almost as large an acreage in meadows. It is evident at this writing that approximately 125,000 acres of winter wheat has been destroyed, and at least 100,000 acres of tame hay, (timothy, clover, and alfalfa). No attempt is made herein to estimate the monetary value of crops destroyed; of farm property, including live stock, stored grain, and feed; of city property (mainly in

Beardstown); drainage district levees; public highways; transportation lines and other public service properties; or the loss to business in general through suspension; as it has been impossible up to this time to procure accurate and comprehensive figures; but the final count will unquestionably run into the millions. The city of Beardstown with its environs suffered the most extensive loss of any one locality and the loss there will no doubt exceed a million dollars.

"The details of flood development in the Illinois River valley, arranged chronologically, are as follows: On April 1st, Beardstown, a city of 8,000 people, situated on the east bank of the Illinois River, in Cass County, with the water at a stage of 19.1 feet and rising steadily, was experiencing trouble with seepage as it had often done in other years. But alarm was not felt until about the 5th when a stage of 20.3 feet was reached, and sand bags were brought into use to strengthen the weak places in the various levees protecting the city. On the 7th, with the gage reading 21.8 feet, which had been equalled but twice (February 25, 1883 and April 5, 1913) since 1844, it was apparent that the city was in danger of the greatest flood in its history. The Lost Creek levee, just north of town, and the Combs (or City) levee were both threatened and heavy seep water was rapidly filling up the low places in the Combs addition, where the water stood 3 to 12 feet deep, and 30 families were driven from their homes. On the 8th, the water level was temporarily at a standstill due to some small levee breaks north of Havana. On the 9th, the stage had reached 22.1 feet; the water was going over the northwest approach to the Illinois River bridge and the bridge was closed to traffic; telephone lines into Schuyler County were swept away; high winds during the night had brought the water over one levee and one-fourth of the town was under water and all basements flooded; city was surrounded by water on west, south, and east. On the 9th, the Fairbanks levee in Greene County, opposite Kampsville, broke at 2 p. m., flooding 10,000 acres and driving out 40 families; many houses standing in 9 feet of water. On the 10th, the river at Beardstown reached the stage of 22.4 feet; 30 city blocks were under water and 65 families had been forced to leave their homes; all levees threatened. The Thompson Lake levee, opposite Havana, broke, flooding 7,000 acres. On the 11th, the Combs levee at Beardstown broke at 11:10 a. m., bringing the total number of city blocks affected up to 60, and the number of homes to 200; many sections of city flooded for first time in history; schools closed; more highways leading into city cut off. On the 12th, with a stage of 22.7 feet, the highest in history so far, the County levee gave way at 8:30 a. m., flooding 5,000 acres, and cutting off remaining roads, which isolated city so far as highways were concerned; water was threatening the B. & O. and C. B. & Q. tracks; several buildings settled, breaking plate glass windows; number of blocks inundated had reached 90; families were living on second floors or in tents on high ground. A 500-foot section of the Dyke road opposite Pekin gave way at 6 p. m., flooding the Lamarsh Drainage District of 3,500 acres and driving out 50 families; a 500-foot section of the Peoria and Pekin Terminal Railway was washed out after the Lamarsh levee broke, and the new hard road west of Pekin was submerged and closed to traffic (the water did not leave the pavement until May 18th). At Peoria, the water reached the foot of Main Street and entered basements of practically all business houses along the river front but the loss was negligible. At Petersburg, on the Sangamon River (tributary to the Illinois), the water was washing over dykes and 10 blocks were under water. On the 13th, the lower part of Lost Creek levee broke, flooding 2,000 acres and washing out the B. & O. trestle and covering the track, forcing the suspension of traffic; 100 blocks of city were now under water at a depth ranging from 1 to 8 or 10 feet generally and to 15 feet in the Combs addition; only a few streets unaffected; water at door of post office; rubber boots and boats brought into general use and all stocks of the former exhausted. At Frederick, across river from Beardstown and 4 miles north, the flood conditions were serious and two-thirds of the town was under water. On the 14th, the Kelly Lake levee, above Browning, Schuyler County, broke, flooding 3,000 acres. The C. B. & Q. track north out of Beardstown was under water and traffic sus-



Cairo, Illinois. Cairo-Mound City Interurban. Taken from back end of car. Concrete road shown by lines of stakes.

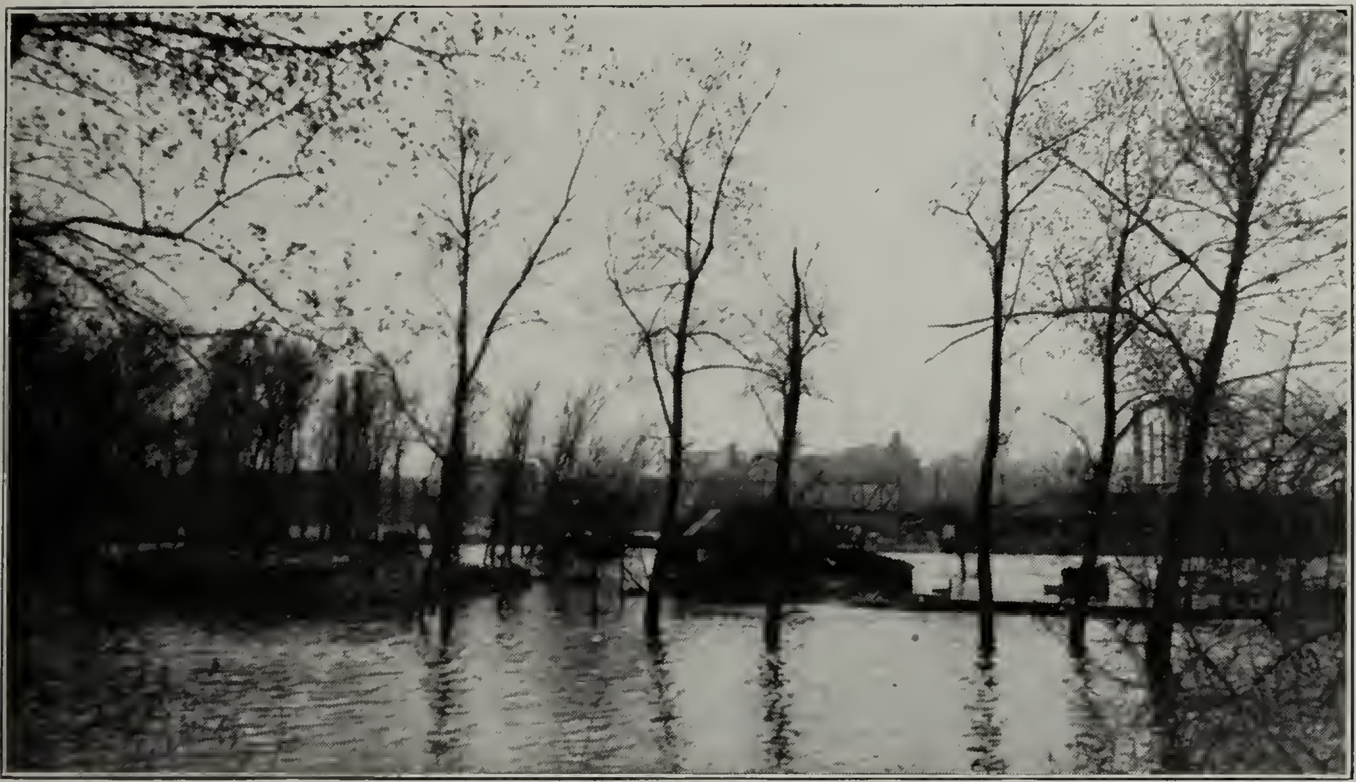


Newton, Illinois. Embarrass River. Down stream from highway bridge.

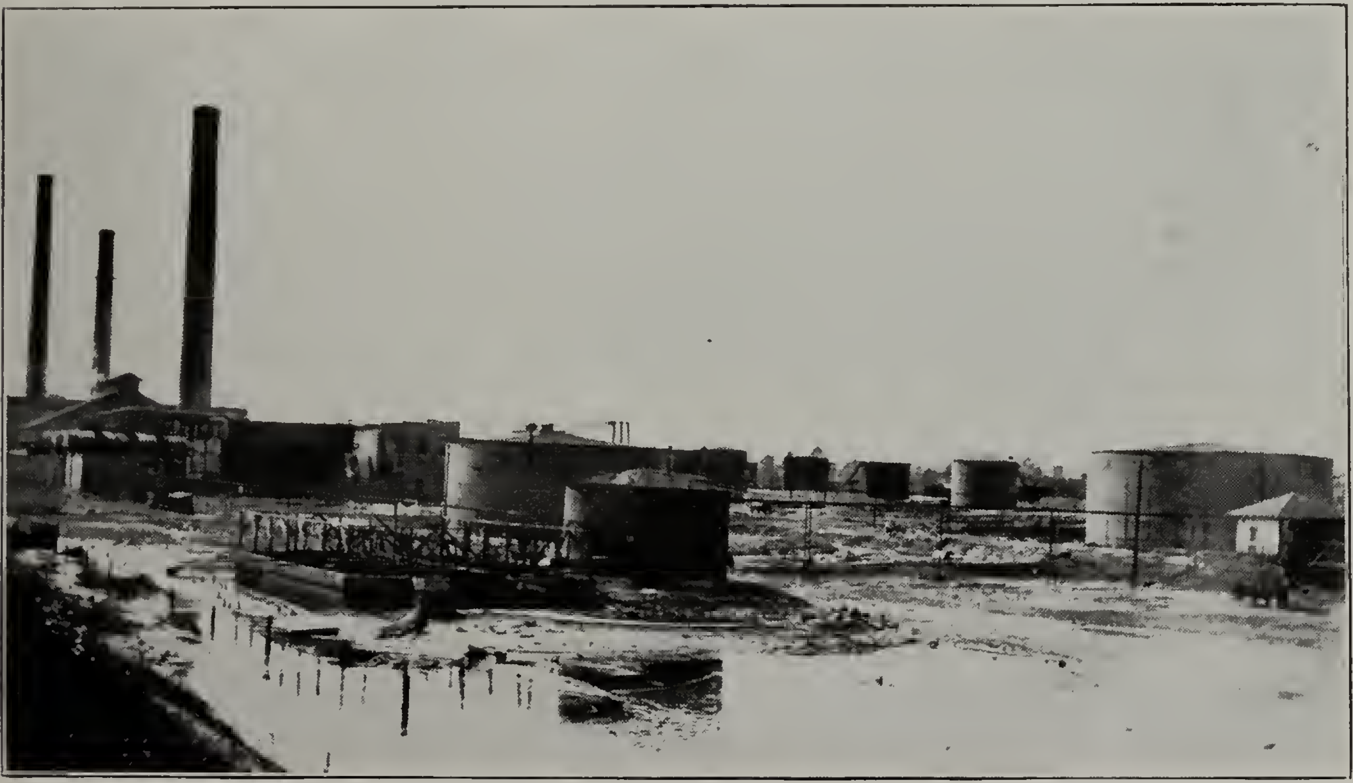
pended; track south of city under one foot of water, this being the sole remaining outlet except by boat; the B. & O. trains were being run over this line south to Jacksonville; to date, about 300 families had been driven from their homes; almost all of the levees in vicinity of Beardstown had either been crevassed or had water coming over the top; river reported to be 18 miles wide, extending from bluff to bluff; about 70 per cent of the city now under water. East Peoria was threatened and families were moving out. Trains were entering Peoria through 6 inches of water for two blocks. C. & N. W. and Peoria Terminal tracks washed out opposite Pekin. At Pekin 15 families driven from homes; C. & N. W. tracks south out of Pekin under water and service suspended. By the 16th, the river at Beardstown had reached a stage of 24.7 feet and the city was completely surrounded by water; number of vacant houses had increased to 350 and the number of inundated blocks had increased to 133; only 8 business houses were dry on main floor and all streets were under water. The Coal Creek levee, opposite Beardstown, was crevassed at 6:30 a. m., exposing 7,000 acres to the flood waters; water rushed through the break, carrying four loaded flat cars, one of which was carried one-half mile; 50 families were driven out and 60,000 bushels of corn destroyed; loss of livestock was large; some of the farms under 15 feet of water. On the 17th, the Scott County levee was crevassed near Naples and 12,000 acres inundated; a 1,500-foot section of the Wabash track was washed out; 4 miles of the track under water and service suspended. On the 18th, freight service over the C. B. & Q. south out of Beardstown was suspended, although passenger trains continued over the submerged line; all food was brought in by boat after that; 1,200 feet of the C. B. & Q. track north washed out and the road bed several feet under water. On the 19th, the Meredosia Lake levee, 4 miles north of Meredosia, broke at 12:30 p. m., flooding 8,000 acres and driving out 50 families. The breaking of this levee destroyed a section of the electric power line from Keokuk supplying the city of Beardstown. Repairs were begun at once and the line restored within 14 hours, during which interval the emergency power plant at Beardstown was utilized. All business houses in Beardstown were now inundated except the post office, and 20,000 acres of land around the city were under water. The town of Naples was entirely surrounded by water and but one dry spot left in the town, where all inhabitants were huddled together. Suffering was apparent and aid was supplied from the outside. The Hartwell levee, west of White Hall, broke during the night of the 18th-19th, flooding 8,000 acres. On the 20th, the river at Beardstown reached the stage of 25.1 feet, the crest of the flood, which was 2.6 feet above the previous record, and remained at that level from 6 a. m. to 7 p. m., when the Crane Creek levee broke, flooding 6,000 acres, and the waters started to recede. It was estimated that 85 per cent of the city was under water at the time of the crest and that at least 1,200 homes were affected. Through the breaking or washing of levees already mentioned and others, including the Liverpool, in Fulton County, exposing 5,000 acres; Quiver, above Havana, flooding 5,000 acres; and others; a vast area of farm lands in the counties between Peoria and the mouth of the river, and those along the Sangamon tributary, was inundated, with almost inestimable loss to crops and property. Accurate and complete estimates have not been obtainable as yet, but it is believed that the total acreage flooded exceeded 175,000 acres. By the 21st, the river at Beardstown had fallen 6 inches due to the Crane Creek levee break. Suffering was becoming marked and the city called for outside help in food, clothing, and cash, which was responded to promptly. From this time on the descent was gradual. Some houses were floating about and causing added destruction, one having snapped off 72 telephone poles. Telephone communication with points across the river in Schuyler County was reestablished. More or less suffering was reported from Naples and Meredosia. A 600-foot section of the new hard road between Rome and Mossville, Peoria County, was under water and closed to traffic; a 300-foot section of the hard road 1 mile south of Sparland, Marshall County, moved 3 or 4 feet toward the river due to settling downhill of the grade foundation. On the 24th, the C. B. & Q. ran their first train north out of Beardstown over a temporary trestle 500 yards long, constructed over the submerged track. By the 28th, the river at Beardstown had fallen 1.7 feet and many business houses again open. Streets were beginning to show and work of cleaning began. On April 30th, the river at Beardstown had fallen to 22.8 feet and conditions were rapidly getting back to normal, with shoes and automobiles coming into use again. Most merchants expected to reopen for business on May 1st. City was accessible from outside by automobile but unimproved roads heavy. The B. & O. expected to resume service on May 1st. As the flood receded, prompt and effective cleaning and liming of all exposed surfaces successfully solved the problem of sanitation that was expected to follow in the wake of the flood. One of the remarkable facts attending the unprecedented flood was that not a single death occurred as a result of the flood either in Beardstown or the Illinois Valley proper, although three deaths occurred in other parts of the State. This absence of casualties is believed to be due largely to the slow approach of the flood crest, the heeding of timely warnings, and the native training that river folk receive, which enables them to quickly adapt themselves to the conditions. Another fortunate feature was the somewhat remarkable feat of maintaining practically uninterrupted gas and electric service under such unusual and trying conditions. On May 8th, schools reopened and the C. B. & Q. recalled their 600 shopmen. By May 20th, the river had fallen 10 feet and the flood had subsided almost entirely, although there was still some water in the Combs addition that had to be pumped out."

CONCLUSIONS.

1. The 1922 flood must be expected to recur probably once in ten years.
2. Greater floods must be expected at longer intervals.
3. Water in the Mississippi River at Grafton was relatively low and had the water at that point been as high as at the time of the 1844 flood, the water at Beardstown would have been materially higher and greater damage would have been done to levee districts along the lower Illinois River.
4. The quantity of water discharged at the peak of the 1922 flood was no greater than during the 1904 flood.
5. The increased stage elevations of the 1922 flood over previous floods were due to (a) the construction of levees along the Illinois River which restricted the discharge capacity of the stream and eliminated natural reservoirs, (b) reclamation and drainage of tributary streams permitting greater quantities of water to reach the river in a given period of time, (c) straightening and draining of the Kankakee River in Indiana, (d) addition of approximately 8,000 cubic feet per second of water from another water shed, the Great Lakes, (e) silt brought to the Illinois River valley from tributary streams due to higher velocities created by river improvement.
6. Greater flood elevations must be expected in the future as additional lands are reclaimed and greater restriction is placed on the discharge capacity of the stream.
7. The failure of levee districts at or near the peak of the flood prevented greater damage to other property.
8. The straightening and deepening of tributary streams increases the velocity of water, especially at flood times and causes excessive erosion of banks and beds, which material is carried to lower reaches of the streams and forms thick deposits over the flood plains. This is especially noted in the lower reaches of the Sangamon River and this condition will be aggravated as reclamation of land upstream progresses.
9. Flood heights can be lessened by (a) moving levees back further from the river banks, (b) removing islands from the channel of the stream, (c) clearing islands and shore lines of timber and underbrush, (d) using some of the present levee districts and constructing others for use as reservoirs to be filled when floods reach the danger line, (e) construction of reservoirs on tributary streams.

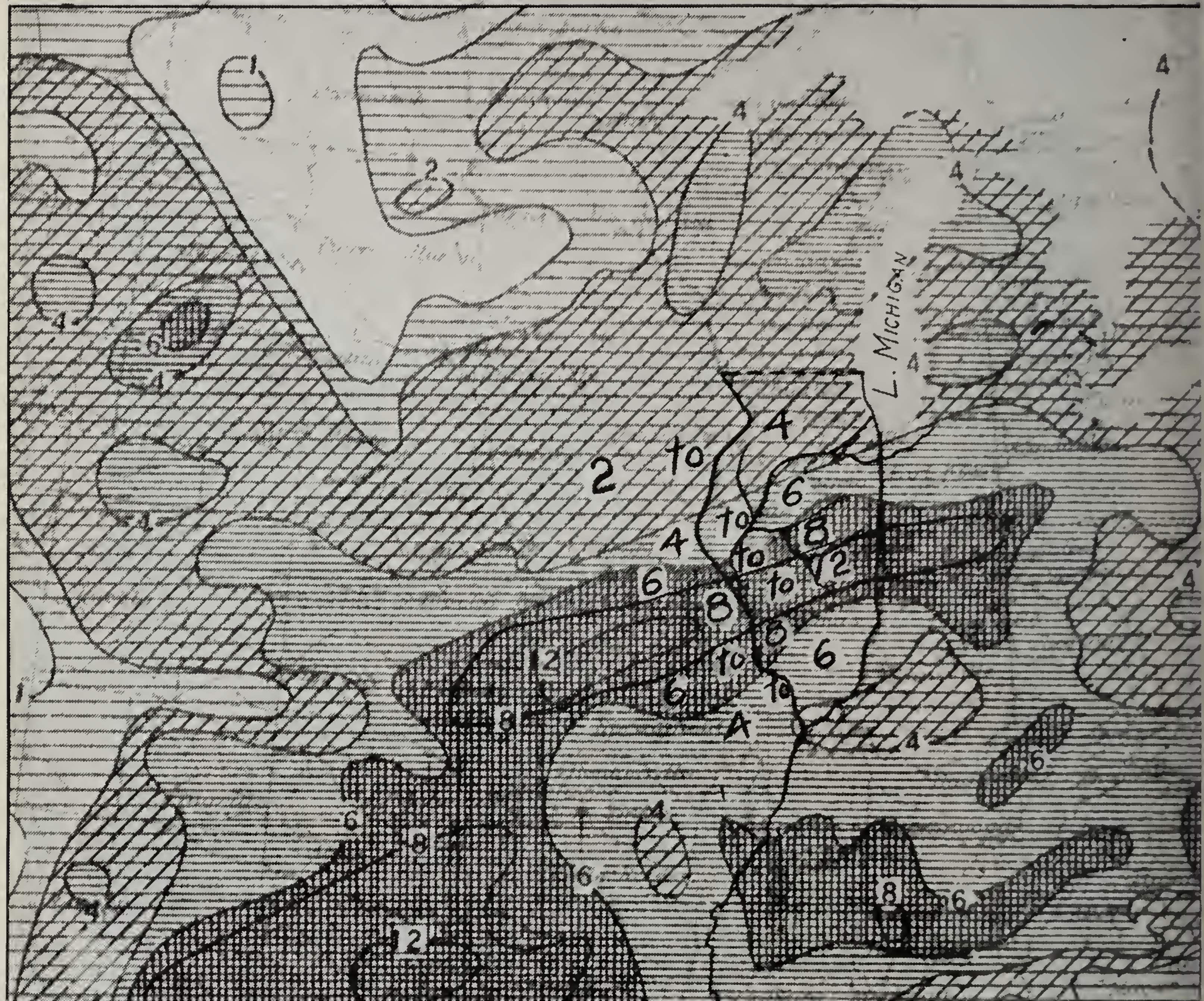


East Peoria District. Taken at intersection of Farm Creek with river and looking towards Peoria.



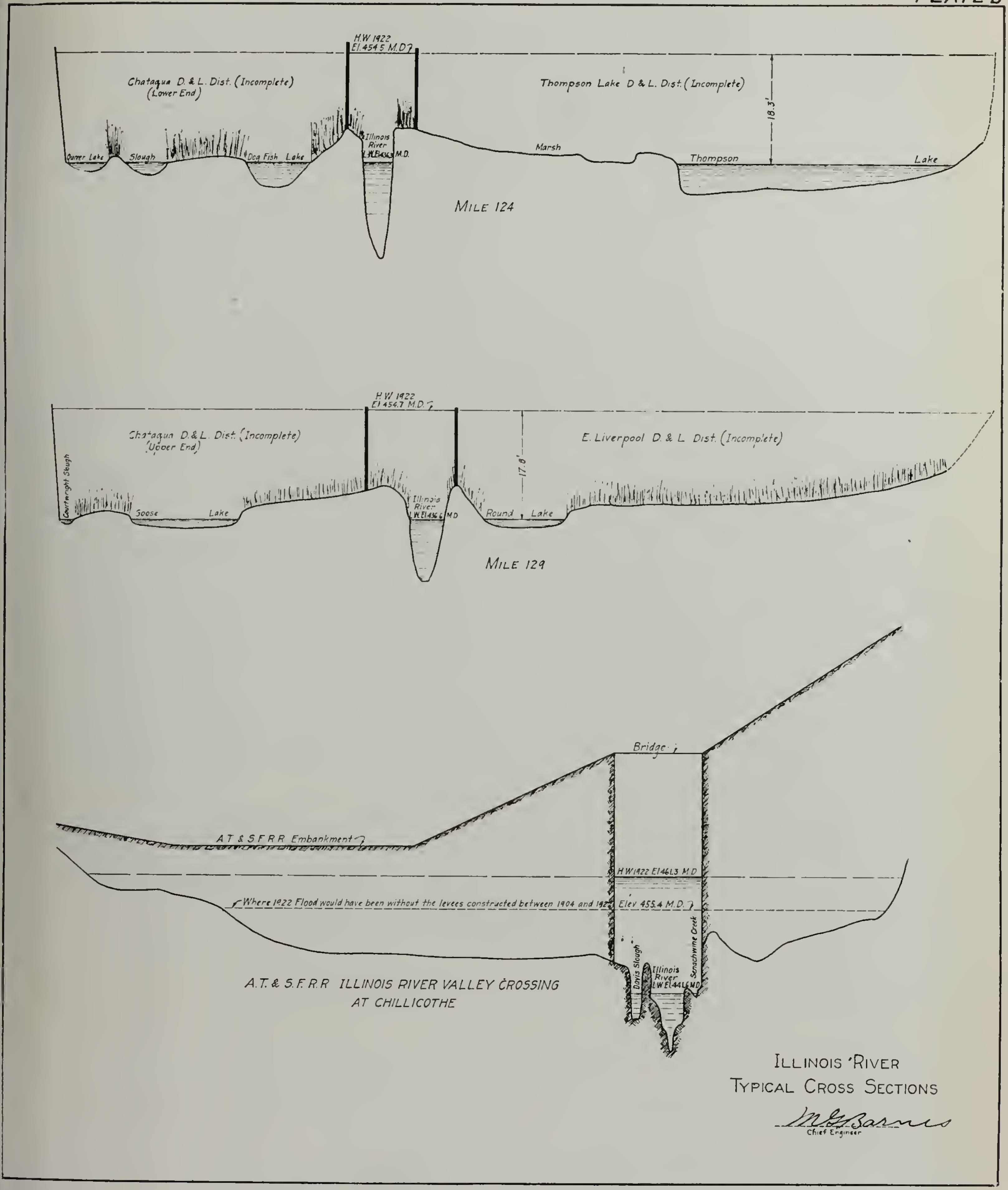
Lawrenceville. Embarrass River. Back water around Indian Refinery. Note—oil on water in lower left showing reflections.

PLATE 1



U.S. WEATHER BUREAU
Total Precipitation, Inches, April, 1922

PLATE 2


H.W. 1922
El. 454.5 M.D.
Chataqua D. & L. Dist. (Incomplete)
(Lower End)
Thompson Lake D. & L. Dist. (Incomplete)
18.3'
Quiver Lake
Slough
Dog Fish Lake
Illinois River
L.W. El. 435.3 M.D.
Marsh
Thompson Lake
Mile 124
H.W. 1922
El. 454.7 M.D.
Chataqua D. & L. Dist. (Incomplete)
(Upper End)
E. Liverpool D. & L. Dist. (Incomplete)
17.8'
Courtwright Slough
Goose Lake
Illinois River
L.W. El. 436.6 M.D.
Round Lake
Mile 129
Bridge
A.T. & S.F. R.R. Embankment
H.W. 1922 El. 461.3 M.D.
Where 1922 Flood would have been without the levees constructed between 1904 and 1922 Elev 455.4 M.D.
Davis Slough
Illinois River
L.W. El. 441.6 M.D.
Senachwine Creek
A.T. & S.F. R.R. Illinois River Valley Crossing at Chillicothe

ILLINOIS RIVER
TYPICAL CROSS SECTIONS

M. G. Barnes
Chief Engineer

PLATE 3

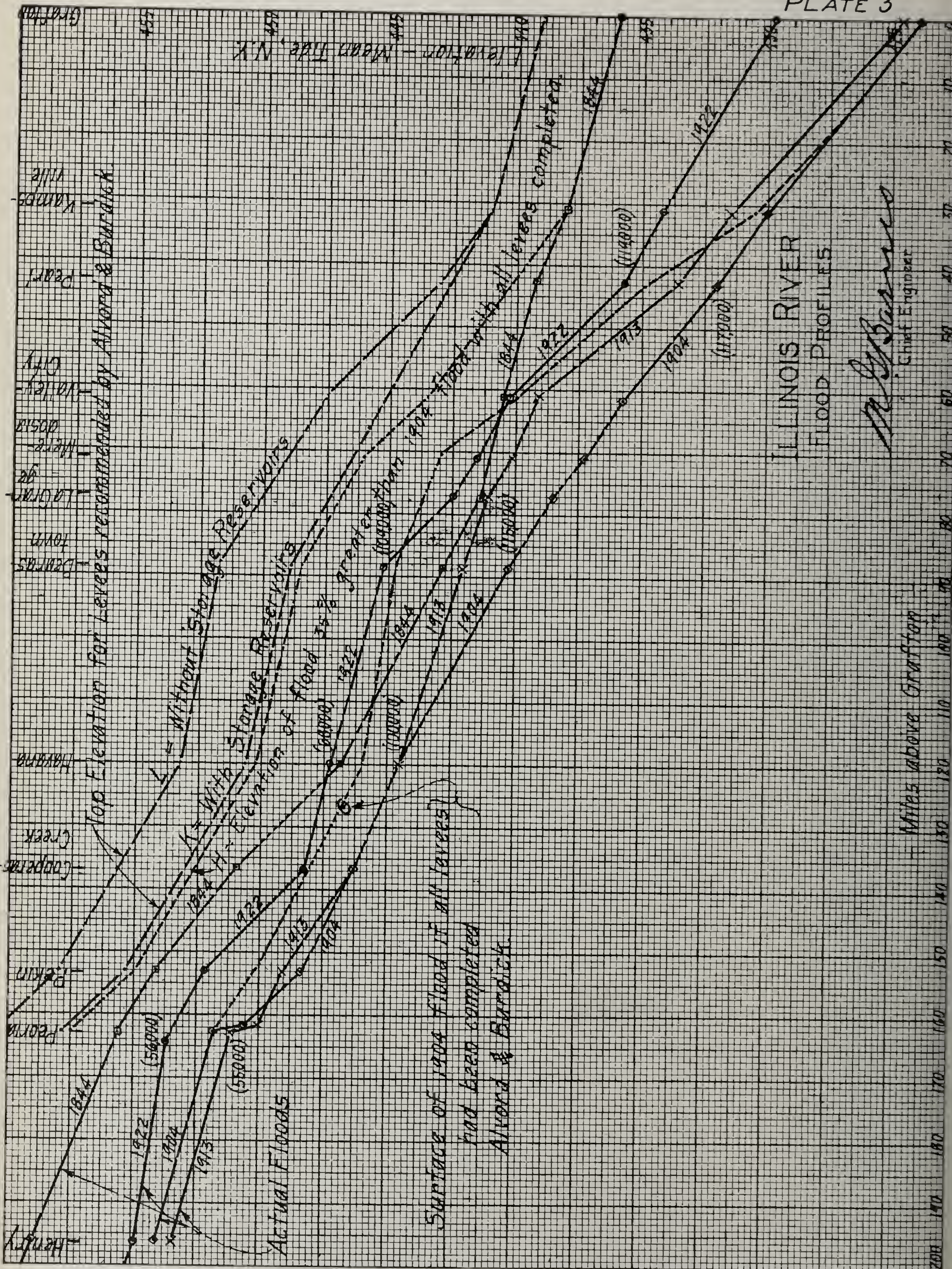
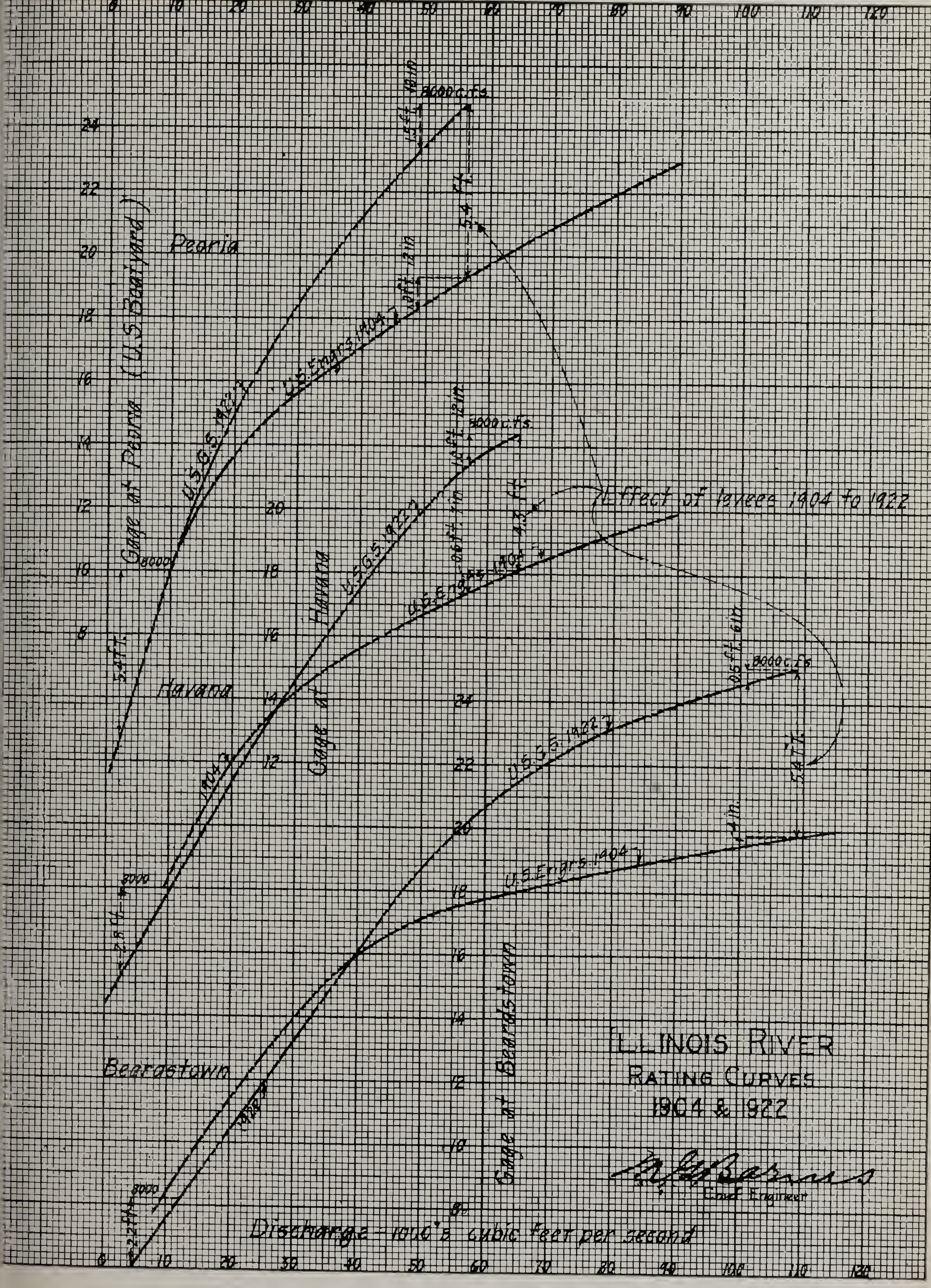

ILLINOIS RIVER
FLOOD PROFILES
Chief Engineer
Top Elevation for Levees recommended by Alvord & Burdick
L = Without Storage Reservoirs
K = With Storage Reservoirs
H = Elevation of flood 34% greater than 1904 flood with all levees completed.
Elevation – Mean Tide, N.Y.
Actual Floods
Surface of 1904 Flood if all levees had been completed
Alvord & Burdick
Miles above Grafton
Grafton
Kampsville
Pearl
Valley City
Meredosia
La Grange
Beardstown
Havana
Copperas Creek
Pekin
Peoria
Henry
1844
1904
1913
1922
(56000)
(5000)
(5600)
(86000)
(104000)
(111000)
(114000)
(116000)
(117000)
435
440
445
450
455
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

PLATE 4



KEUFFEL & ESSER CO., NEW YORK, NO. 334 C.

PLATE 5

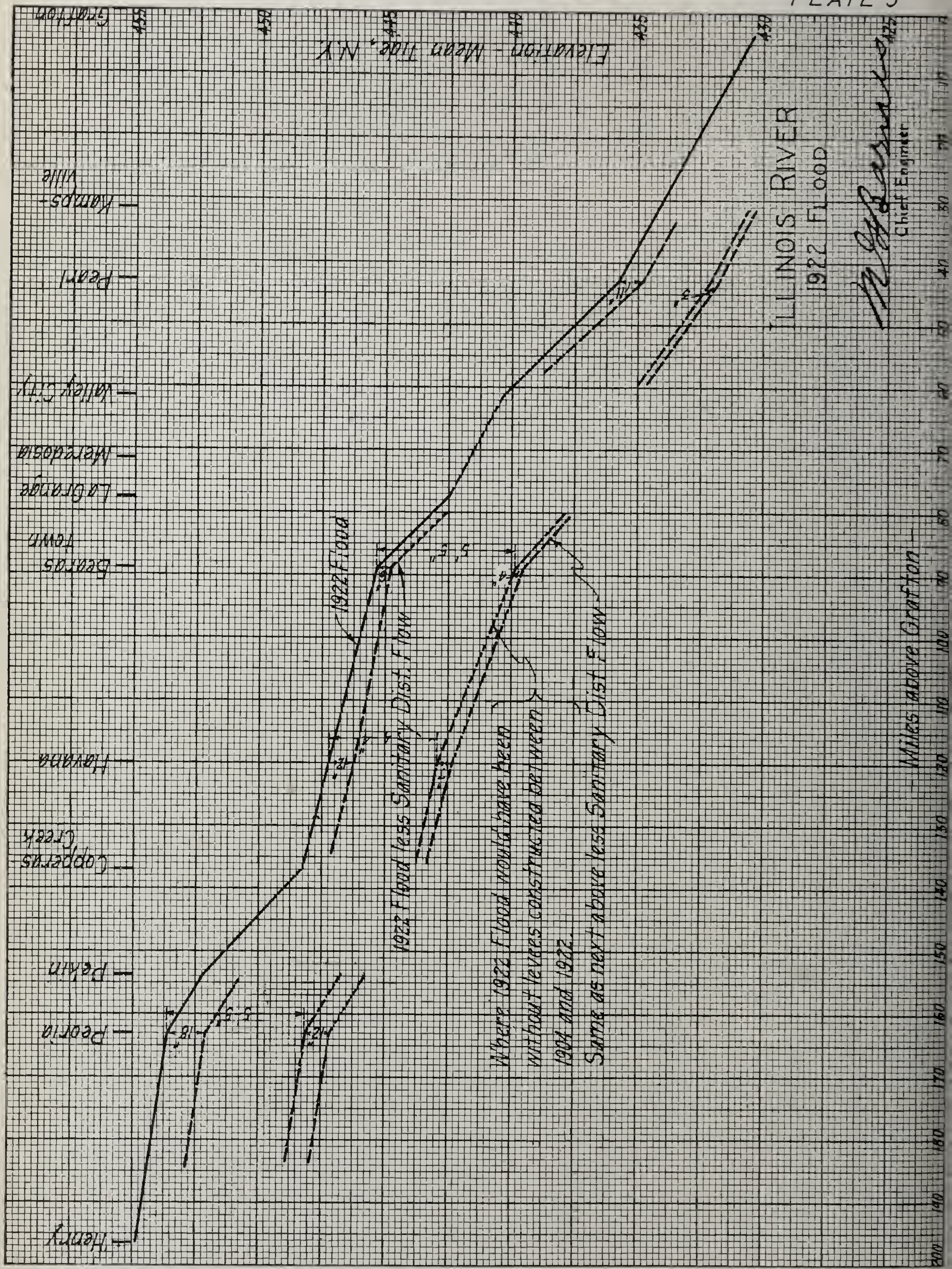

Elevation - Mean Tide, N.Y.
455
450
445
440
435
430
425
Grafton
Kampsville
Pearl
Valley City
Meredosia
La Grange
Beardstown
Havana
Copperas Creek
Pekin
Peoria
Henry
ILLINOIS RIVER
1922 FLOOD
Chief Engineer
1922 Flood
1922 Flood less Sanitary Dist. Flow
Where 1922 Flood would have been without levees constructed between 1904 and 1922.
Same as next above less Sanitary Dist. Flow
Miles above Grafton
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

PLATE 6

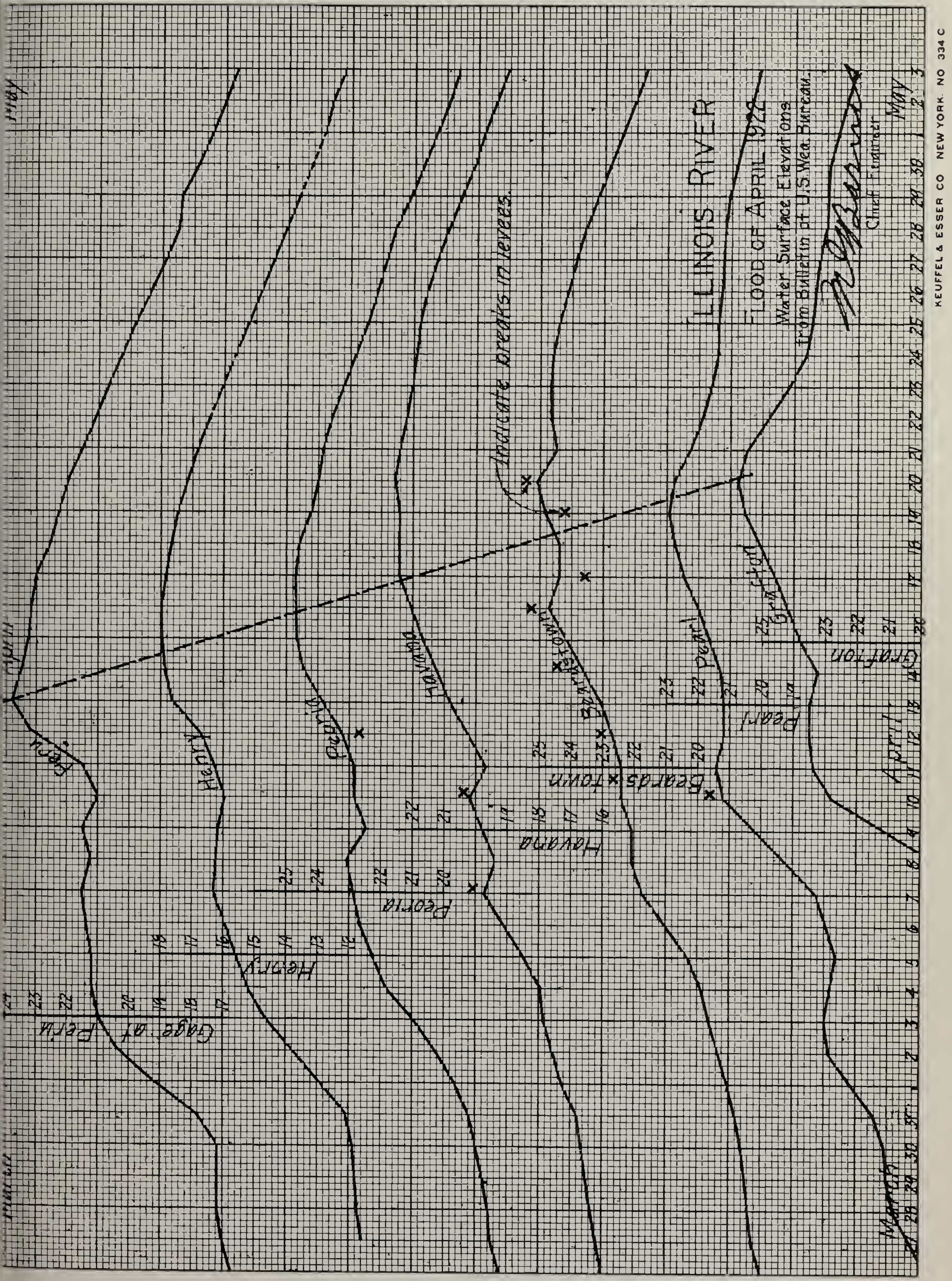
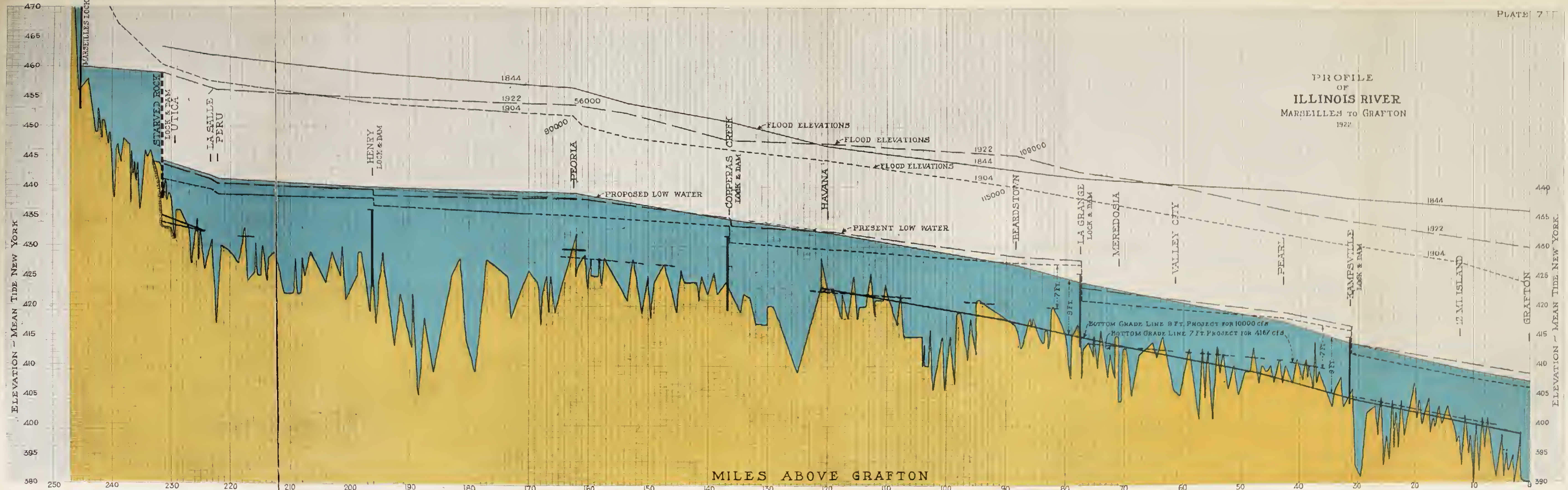

ILLINOIS RIVER
FLOOD OF APRIL 1922
Water Surface Elevations
from Bulletin of U.S. Wea. Bureau.
Chief Engineer
x Indicate breaks in levees.
Gage at Peru
Peru
Henry
Peoria
Havana
Beardstown
Pearl
Grafton
March
April
May
KEUFFEL & ESSER CO NEW YORK NO 334 C

PLATE 7

PROFILE OF ILLINOIS RIVER

MARSEILLES TO GRAFTON

1922



DIVISION OF WATERWAYS.

William L. Sackett, *Superintendent.*

BIG MUDDY RIVER SURVEY.

Improvement of the Big Muddy River in southern Illinois has been the subject of preliminary surveys and estimates of cost to make it navigable for commerce since 1908.

The Fifty-second General Assembly of Illinois made an appropriation for completing the survey and making a total estimate of cost based upon the conditions found.

In June, 1922, the Division of Waterways assigned Mr. W. G. Potter, one of its engineers, to take charge of this survey and actual field work began on June 13, 1922. Final report was completed December 1. As a result of the complete survey the cost of the improvement has materially increased, a portion of the increase being attributable to the necessity of storage reservoirs to impound water during the rainy season to maintain levels of navigation during the extreme low water periods of the dry portions of the year. Also the cost is increased considerably by the extension of the survey 28 miles further upstream than the old report, in order to include Franklin County in the improvement.

The estimated cost of one route suggested is $4,279,364. The other route is $3,175,346. The first route is 21 miles shorter than the less costly plan.

Mr. Potter's report follows:

INTRODUCTION.

The problem of moving coal from mine to market, in the valley of the Big Muddy River, has been receiving increasing attention for the past fifteen years, because of the rapid increase in the number of mines and of their output.

The first step towards improving or canalizing the river was by a survey in 1908 to 1910 made jointly by the United States and State Geological Survey. This was followed in 1912 by a detailed survey of the river from its mouth to the Illinois Central Railroad bridge south of Zeigler. In 1916 further investigation was made with a report to the legislature. In 1919 again a report was made by the Division of Waterways with a revised estimate of cost.

Finally the legislature, in its session of 1921, asked for a new and complete report on the proposition.

In compliance with this, the Division of Waterways placed a party in the field during the summer of 1922, and surveys were made connecting with the previous survey and extending the proposed improvement to the north line of Franklin County. This consisted of a stadia survey from the end of the old survey, along the river bank to the site of the reservoir near the north end of Franklin County. Also lines of check levels from U. S. bench marks and soundings of the river were taken approximately at thousand foot intervals. A survey of the reservoir site to show area and volume obtainable was made. A complete transit survey was also made with topography and levels on the proposed cut-off from near Sand Ridge to the Mississippi, and at the site of the entrance dam near the Mississippi, borings were made fifty feet or more below the surface to see if rock could be found at any reasonable depth.

This report, therefore, covers the feasibility and cost of improving the river from its mouth up to Jefferson county by cutting off the worst of the bends, dredging and widening where necessary, and installing locks and dams, to give an eight foot low water channel for the entire distance. Because of the extreme low water in the dry part of the year the natural flow is insufficient to furnish enough water for lockage and other necessities. Therefore, plans and estimates are also included for a storage reservoir at the upper end of the improvement.

Also, as a part of the report, is an alternative route by which the improvement would be materially shortened by a cut-off from near Sand Ridge to the Mississippi River, with its cost and feasibility.

All elevations used in this report are based on the mean sea level as the datum plane.

The report follows as indicated below:

Chapter 1. Resources and Transportation.

Chapter 2. Rainfall.

Chapter 3. Route One via cut-off Channel.

- (a) General description.
- (b) Locks, bridges and special features.
- (c) Excavation and cut-offs.
- (d) Right of way and flooded area.
- (e) Resume of cost.

Chapter 4. Impounding Reservoir.

- (a) General description.
- (b) Dam.
- (c) Area and cost.

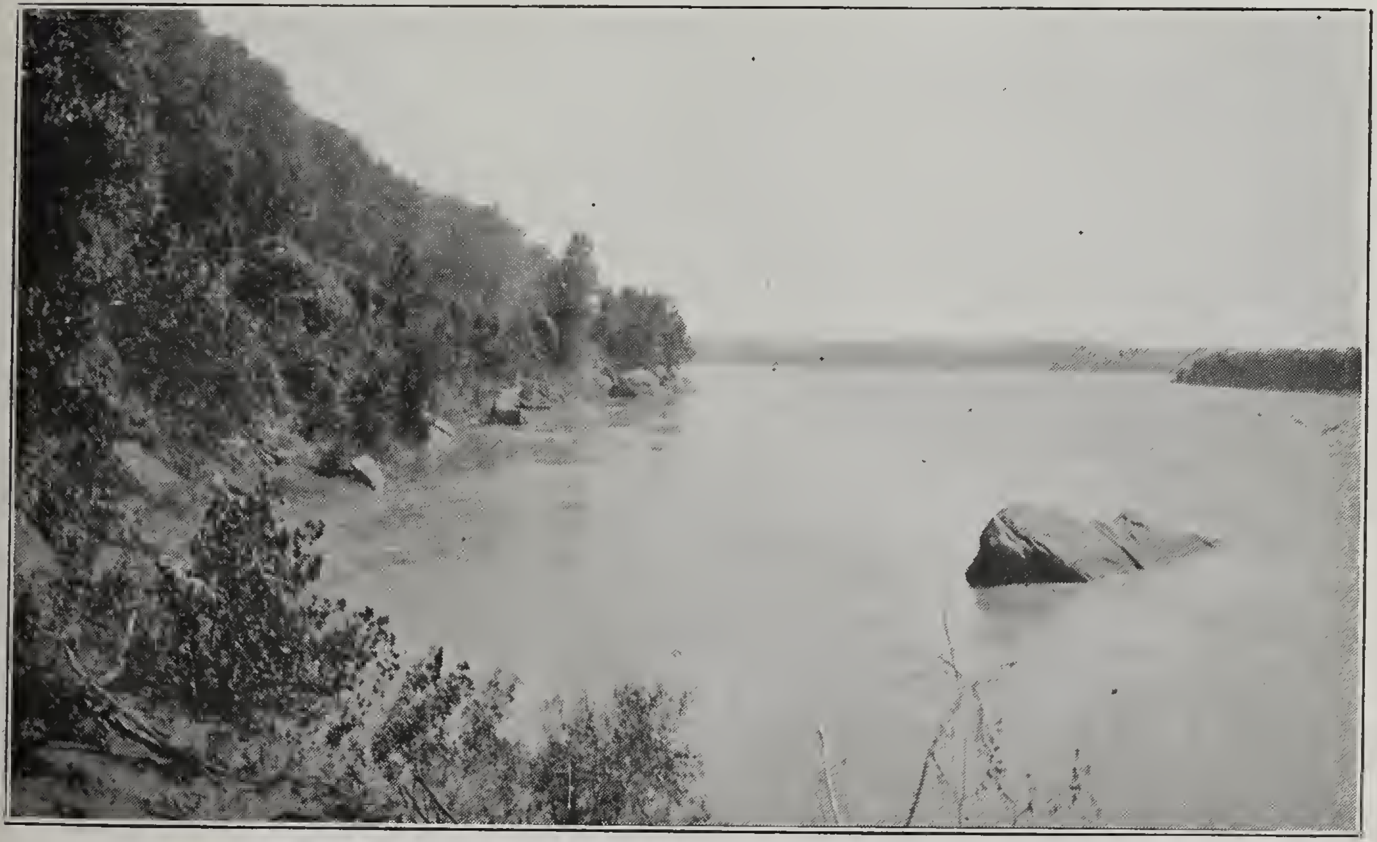
Chapter 5. Route Two—All River Route.

- (a) General description.
- (b) Locks, bridges. and special features.
- (c) Excavation and cut-offs.
- (d) Flooded area.
- (e) Resume of cost.

Chapter 6. Advantages and Disadvantages.

Chapter 7. Recommendations.

Mississippi River at Outlet of Proposed Cutoff Channel.



Mississippi River Just Below Outlet of Proposed Cutoff Channel.

CHAPTER I.

RESOURCES AND TRANSPORTATION.

Growth of a city, state or nation depends upon its transportation facilities.

No community, no state, however well equipped with agricultural, mineral or manufactured products, can grow or expand properly unless those products can be quickly and economically transported to the consumer. No state can live entirely unto itself. Without some economical means of transportation none of our states could have reached their present development, nor could they long maintain it. None can supply their people with all the commodities requisite for their health and enjoyment. Some states furnish iron or copper or gold to other states, and receive in return fuel and food supplies. Some furnish cotton or grain exchanged for coal or ore. Each is dependent on others for some of its requirements.

General William M. Black, Chief of Engineers, U. S. A., before the National Rivers and Harbors Congress in 1916, spoke as follows concerning transportation:

> "To my mind we have hardly any need of greater importance to society in general than the need for better transportation facilities—transportation facilities which will, at the least cost, transfer from the point of production, no matter where in the world, to the point of consumption, no matter where in the world.
>
> This 'high cost of living', of which we all complain, is not altogether a bad thing when you come to consider it. I think it may be safely said that it is, after all, in certain of its aspects, a measure of the growth of civilization. Naturally we all want to live well—and by living well I mean living decently, properly nourished, properly clad—necessarily there is a greater demand for the things that go towards that. That greater demand then requires increased production, and, unless satisfied, necessarily carries with it increase of price.
>
> Now there is no place in the world, no place in our great broad country, which does not or can not produce something—be it the product of the mine, the product of the forest, of agriculture, or of manufacturing—more cheaply than can be done at any other point. Therefore, true economy and efficiency in the national conduct of affairs would have the thing produced at the point of least cost, and then have distribution made in the manner that is least expensive, and in that way the interests of all will be best served.
>
> We have witnessed a tremendous growth of the railways in our country, and we have seen, with that growth in many sections a diminution of water traffic; yet these two means of transportation are not antagonistic at all. In all the older sections of the country the enlightened heads of railroad companies recognize that water transportation is an economical thing for them; for it permits an excess of coarse or low-grade freight which they can not carry except at a loss but which they must carry if presented to be disposed of in another way thus making possible the handling by their lines of a larger amount of a better paying class of traffic. * * *

So there is ample room, as well as the utmost need, for the development of all routes of transportation, be they by rail or by water.

Now there have been a number of reasons for the decline of water traffic, and for its apparent inability, in certain cases, to compete with the railways. These are almost invariably from causes which can be removed; and I want to invite the attention of this convention briefly to some of them, because it is certainly useless for us, or for anyone, to advocate an immense investment of the people's money in the improvement of waterways unless those waterways are economically useful and—they are only economical where used. Today I think it is the duty of all citizens, especially those interested in waterway development, to try and see how such waterways can be usefully employed.

On the Mississippi River we have an improved waterway, of ample depth and sufficient width and open the year round, from St. Louis to New Orleans; but it is only just within the last year or two that that waterway has begun again to be used and used in a rational way. * * * I feel quite confident that within the next few years we will find a great and legitimate growth of commerce on the Mississippi.

* * * The cheapest transportation in the whole world is probably by the great tramp steamers of the seas; but next cheapest is on the steamers of the Great Lakes, where iron ore is transported and delivered at a cost of from seven-tenths to eight-tenths mill per ton-mile. On the Ohio and Mississippi Rivers those great coal fleets, returning empty and so earning nothng on the return journey, can carry their coal at a rate of six-tenths mill per ton-mile. The maximum cost of carrying coal in this way would probably be about 1 mill per ton mile; whereas the lowest known rail rates on coal are 2½ mills per ton-mile, or just two and one-half times the amount of its maximum cost by water. So that anyone who really goes into the subject carefully will see that there is an absolute need for both rail and water facilities; that even in the poorest districts of our country traversed by the greatest arteries of water transportation that we have, the Mississippi River system, or the Hudson River system, or the others, parallel railroad lines flourish, and they both have a full use for their means of transportation. * * * I will give you just one example. You have heard something said about the decline of the coal traffic on our western rivers. Here are some figures which have just come to hand. On the Monongahela River the tonnage has actually doubled within the last fifteen years. Today it amounts to 12,700,000 tons. In addition to that, letters are on file in the engineer department from prominent manufacturing firms along the Monongahela and Allegheny Rivers in the vicinity of Pittsburgh, which show that they have already ordered towboats and barges which, within five years, will increase this tonnage by 70 per cent, and that about one-half of this increase will probably come within the next eighteen months.

We have example before us, everywhere, of the advantage of properly conducted waterway transportation. I think it is best for us in each case to study what would be the proper method of conducting transportation on each of the waterways in which we are interested, and to put into it the same amount of brains, the same amount of trouble, and if necessary the same amount of money as a railroad always does in bettering its equipment and lessening its cost of operation."

Illinois is fortunate indeed in finding below the surface vast quantities of oil and coal which supply not only the needs of the immediate vicinity of the mine, but also furnish an immense amount to fill the needs of Chicago, St. Louis and the western and southern Mississippi valley.

The valley of the Big Muddy River, including most or all of the counties of Jackson, Perry, Williamson and Franklin, has in the last twenty years come into its own as the producer of a vast and increasing amount of bituminous coal of excellent quality.

Williamson County alone, since 1910, has produced 109,312,310 tons, and altogether over 150,000,000 tons. Franklin County, since 1910, has produced 105,359,640 tons, with a total production of about 111,000,000 tons.

The total production of the four counties in the Big Muddy valley since 1910 is over 253,000,000 tons.

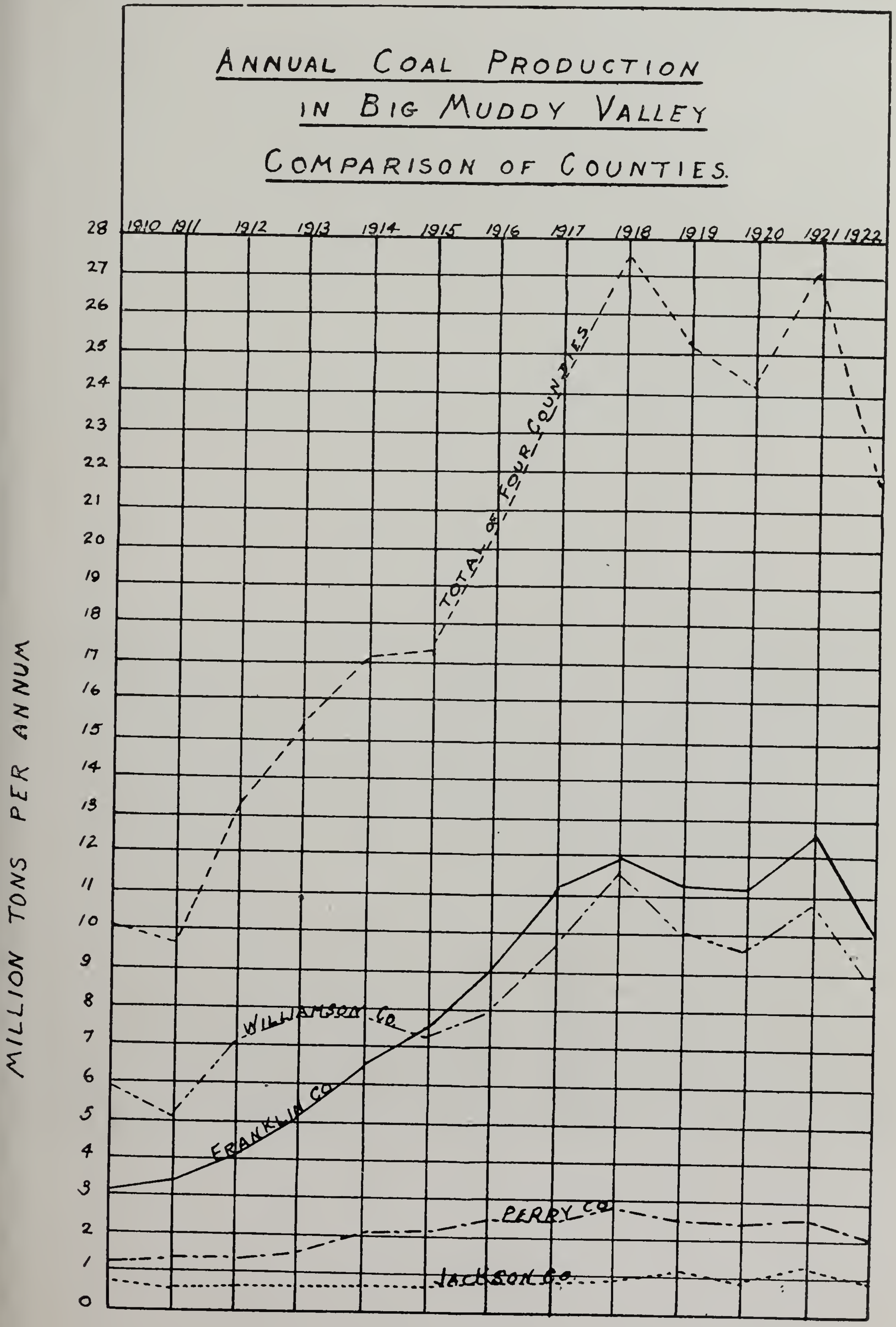
Below is given a chart showing for each year since 1910 the production of the four counties, the total production of the State and the percentage of the valley to the state production. Also it will show the number of shipping mines and local mines for each county.

COAL PRODUCTION OF BIG MUDDY VALLEY
AS COMPARED WITH STATE.

	Franklin Co.			Williamson Co			Jackson Co.			Perry Co.			Total				Whole State
	Shipping Mines	Local Mines	Coal Tons	Shipping Mines	Local Mines	Coal Tons	Shipping Mines	Local Mines	Coal Tons	Shipping Mines	Local Mines	Coal Tons	Shipping Mines	Local Mines	Coal Tons	Per cent of State output	Coal Tons
1910............	10	0	2,071,143	38	17	5,908,544	10	11	762,741	18	5	1,283.094	76	33	10,025,522	21%	48,717,853
1911............	14	1	2.356,439	38	12	5,212,749	9	17	648,551	21	2	1,451,080	82	32	9.668,819	19%	50,165,099
1912............	16	0	4,026,815	34	12	7,086,544	7	14	724,374	19	5	1,406,317	76	31	13,244,060	23%	57,514,240
1913............	16	0	5.232,526	35	11	7,709,110	8	12	727,484	18	5	1.643.043	77	28	15,312,163	25%	61,846,204
1914............	19	0	6.595,799	33	9	7,710.740	7	13	749,445	16	6	2,052,148	75	28	17,108,132	28%	60,715,795
1915......	18	0	7,324,644	29	14	7,216,188	5	11	622,318	10	7	2,173,834	62	32	17,336,984	30%	57,601,694
1916.......... .	19	0	9,070,811	30	12	7.904.528	6	15	821.121	11	8	2,509,016	66	35	20,305,476	32%	63,673,530
1917............	21	0	11,317,657	35	9	9.666.302	6	12	818,571	11	8	2,477,561	73	29	24,280,031	31%	78,983,527
1918............	24	0	12,007,397	42	12	11,655,101	8	12	975,141	14	5	2,937,237	88	29	27,574.876	31%	89,979,469
1919............	24	0	11.332,912	40	9	10,052,578	7	17	1,146,176	18	2	2,696.984	89	28	25,228,650	34%	75,099.784
1920............	26	0	11,299,280	43	13	9,631,386	7	12	927,221	19	5	2.408.900	95	30	24,266,787	33%	73,920,653
1921............	26	0	12,723.700	50	22	10,822,566	8	17	1,204,949	20	7	2,570.264	104	46	27,321.479	34%	80,121,948
1922............	25	0	9,999.917	50	28	8,735,964	9	19	993,240	17	12	2,071,447	101	59	21,800,568	34%	63,276,827
Total......			105.359,040			109.312,310			11,121,332			27,680,925			253,473,607	29.4%	861,616.623

On the map of the Big Muddy watershed, found in the appendix, is shown the name and location of practically all of the mines and also a shaded belt with radius of five miles from the river. The mines within that ten mile strip produced in 1921 about 17,500,000 tons of coal, nearly all of which would be available for water transportation if the river were improved.

Also, with this is a profile chart showing graphically the production of each county, and of the four counties together for each year from 1910 to 1922. On this chart two peaks are noticeable, one in 1918 due to the unusual production caused by the war period, and one in 1922 caused by the falling off in production due to four months of strike.



Plumfield Highway Bridge over Big Muddy.

Ford in Big Muddy—southwest of Benton. Rock outcrop showing on right.

CHAPTER II.

RAINFALL.

The Big Muddy valley lies in the great storm belt of the country, and is subject to periodic rainfall of extreme severity. The general trend of storms, according to the studies of the Miami Conservancy, is from Texas towards the northeast up through southern Illinois, Indiana and Ohio. To show the extent of excessive storms the following table is made up from the United States Weather Bureau statistics for five towns situated either in or very close to the Big Muddy valley. Benton, Carbondale, DuQuoin, Mt. Vernon and Nashville being the points selected. The records of these towns were found for various periods extending from ten to twenty-five years. These are tabulated as follows:

AVERAGE RAINFALL MAXIMA IN FIVE TOWNS.

Storm Period	Inches of Rainfall Benton	DuQuoin	Mt. Vernon	Nashville	Carbondale	Average
1 day........	4.31	5.04	4.36	5.03	4.50	4.65
2 days......	5.30	6.12	8.40	8.96	8.67	7.49
3 days......	6.00	6.85	8.71	8.96	9.74	8.05
4 days......	6.05	6.85	8.76	9.73	9.74	8.23
5 days......	7.40	6.85	8.76	9.73	9.74	8.50
6 days......	7.45	7.05	10.41	11.43	9.74	9.22

This shows very excessive rainfalls not only for a one day period but all the way to the six day period.

In monthly and annual rainfall, however, this territory is not exceptional either for wet or dry periods. There are of course occasional years when the fall season is very dry with a consequent very low discharge in the stream; but the average rainfall for a period of years shows no great departure from the normal.

In the appendix hereof will be found a chart showing graphically the monthly rainfall at each of the towns above mentioned for all the years given in U. S. Weather Bureau reports, and also the average of all these towns for the same periods.

The following tabulation, gives the average rainfall for each month and for the year for the same towns. Some of these records are incomplete in various years, so that lines are drawn in the tabulation to indicate the number of towns in each average.

RAINFALL IN BIG MUDDY VALLEY.

Average of 5 Towns.

From U. S. Weather Rept.

Year.	Monthly precipitation in inches.												Annual Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
1895......	......	1 Town 0.20	3.02	1.99	2.23	2 Towns 2.29	5.60	2.67	2.29	0.58	5.12	4.75	....
1896......	1.64	2.22	3.67	2.03	8.22	3.41	5.77	2.03	6.19	1.86	3.10	0.29	40.43
1897......	3.31	2 Towns 2.98	10.44	5.08	1.88	7,49	3.00	0.77	0.41	0.56	4.00	1.89	41.81
1898......	5.86	1.60	11.94	3.54	5.86	5.28	6.43	3.18	4.54	4.41	2.14	2.12	56.90
1899......	3.26	3.38	2.90	2.27	4.19	1.94	1.98	2.40	0.90	3.95	1.30	2.19	30.66
1900......	1.08	2.94	1.43	1.48	5.37	8.35	3.72	1.81	4.07	1.56	3.49	1.67	36.97
1901......	1.37	2.54	3.79	2.51	1.23	2.32	0.69	3.29	1.53	2.25	1.79	4.05	27.36
1902......	1.03	0.86	3.79	1.89	3.47	4.11	2.22	3.07	2.53	0.62	4.68	5.23	34.00
1903......	1.70	3.84	3.58	3.53	2.53	3.68	1.27	3.00	1.96	2.81	0.91	2.30	31.10
1904......	3.00	2.96	9.21	3.90	4.33	4.37	5.43	3.10	4.99	0.41	0.66	2.93	45.29
1905	1.73	1.29	2.73	3,28	2 Towns 2.20	2.18	8.31	2.55	3.07	3.94	2.64	2.76	36.68
1906......	4.30	2.74	5.90	1.14	1.64	2.85	0.77	2.47	6.76	1.89	7.32	3.54	41.32
1907......	7.60	0.73	2.82	2.54	4.85	8.11	3.87	7.04	0.99	2.89	4.21	3.61	49.26
1908......	2.36	7.71	4.36	6.59	5.59	1.06	3.44	1.94	0.96	0.00	2.84	1.38	38.23
1909......	4.51	5.19	5.18	6.49	3 Towns 4.10	3.36	8.40	0.21	5.02	1.10	3.22	3.11	49.89
1910......	1.67	4.14	0.05	4 Towns 3.60	3.15	3.91	5.34	1.88	5.24	7.70	0.80	1.98	39.46
1911......	0.89	3.20	1.61	8.45	1.46	2.06	1.98	5.08	7.82	3 Towns 3.11	2.88	2.52	41.06
1912......	2.16	2.97	4.89	5.59	3.83	5.08	5.18	5.04	3.70	2.02	1.89	0.61	42.96
1913......	7.79	1.01	8.07	2.81	4 Towns 1.75	2.69	2.34	1.83	3.95	5.36	3.63	1.76	42·99
1914......	2.43	3.91	3.42	2.49	0.70	1.30	1.51	4.69	3.25	4.65	0.76	3.58	32.69
1915......	3 T 4.38	2.39	0.65	0.94	8.03	7.51	3.75	10.32	2.01	0.58	2.26	4.97	47.79
1916......	8.92	1.46	1.47	1.68	3.87	4 Towns 6.09	3.12	6.65	2.72	2.72	1.89	3.92	44.51
1917......	4.04	0.63	3.15	7.44	5.07	3.12	3.31	3.48	1.29	3.06	2.25	1.56	38.40
1918......	3 Towns 3.45	0.96	0.94	7.94	6.39	1.81	0.59	4.61	4.71	2.59	2.43	5.06	41.48
1919......	0.98	1.59	3.76	3.55	5.99	6.02	1.17	4.51	2.42	11.75	4.70	0.89	47.33
1920......	4 Towns 2.95	0.81	5.86	3.44	5 Towns 7.02	2.08	3.96	2.85	2.29	2.28	1.14	3.86	38.54
1921......	2.32	1.68	5.53	4.16	2.32	3.61	1.51	6.53	7.11	1.11	6.49	3.39	45.79
Average	3.26	2.44	4.23	3.72	3.99	3.93	3.51	3.59	3.31	2.81	2.91	2.82	40.52

From this tabulation we see that while the dry months of September, October and November are occasionally considerably below the normal, still the average for the period shows nearly three inches of rainfall in each month.

The annual rainfall is also shown with a minimum of 27.36 inches and a maximum of 56.90 inches, the average being 40.52, Only one year out of the twenty-six years shown shows less than 30 inches of annual rainfall.

The discharge or run-off, however, in the upper reaches of the Big Muddy is very low, especially during the fall months, and a storage reservoir will be necessary to assure a flow sufficient for navigation purposes. According to calculations, about 75 cubic feet per second will be the flow necessary to care for lockage, leakage and evaporation.

Gulch in Fountain Bluff. Proposed Cutoff Channel Passes About 600 Feet From Bluff.

Fountain Bluff From Proposed Cutoff Channel.

Chapter III.

ROUTE ONE VIA CUT-OFF.

This route leaves the Mississippi River at a point in Jackson County about two miles west of Gorham, and involves an entirely new channel from there to a connection with the Big Muddy about one mile east of Grimsby station.

For this cut-off channel, which is about 6¼ miles in length, a survey was made to get the alignment, excavation and cost.

The entire line is in the Mississippi bottom, through land largely in cultivation, partly in timber and partly swamp land, all subject to overflow in times of extreme high water from the Mississippi. For about two miles the line skirts the north edge of Fountain Bluff, which is a massive rock formation extending 200 to 400 feet above the plain.

At the mouth of this cut-off, an entrance lock will be necessary to control the passage of boats into or from the Mississippi.

At the upper end of the cut-off, a lock and dam with spillway sufficient for high waters of the Muddy will be necessary.

In addition to these, four bridges, one large culvert and an aqueduct for the Kinkaid Creek will be necessary and discussed later on.

The channel of the cut-off is assumed as seventy-five foot bottim width with slopes of two horizontal to one vertical. The flow elevation would be 362 with 360 as low water flow and 350 as bottom grade.

High water in the Mississippi occasionally gets up to elevation 360 or 362, and the extreme high water record is said to be about elevation 375; but as it would be beyond any reasonable cost to guard against any such flood as this, moreover as such a flood would come so infrequently, it is thought best not to figure on that, but to assume a levee height of 365. The flood of 1920 reached about the elevation of 362.

Excavation. The surface elevations on the cut-off vary from 351 to 363. The grade line as established is elevation 350. The excavation for the channel alone, not including widening for locks or other reasons amounts to 883,000 cubic yards, all of which is earth except for a small amount at the upper dam.

The excavated material would be placed on both sides, the levee on the north side to be raised to 365 elevation, and the balance of material placed on the south side to whatever height it will reach.

The amount of fill necessary for levees on both sides to the elevation of 365 will be about 551,000 cubic yards, leaving 332,000 cubic yards excess to raise the south levee. The object in placing this extra material in the south levee is to stop the flow of exceptional flood waters from north to south and thus prevent the material from washing into the canal and thus filling it up.

Estimating the excavation at forty cents per cubic yard, the cost for this would amount to $353,200.

Entrance Lock (Lock One A on Map.) This lock is to be 300x45 feet in inside dimensions. The material here, from borings made, is earth and water sand to a depth of over 50 feet below the surface. Because of this poor foundation, the construction will be much more expensive than if rock were found at a reasonable depth. Low water in the Mississippi is assumed as elevation 326, and the miter sill of the entrance lock is placed at 319 to allow plenty of room for extreme low water times. The flow line above this lock will be from elevation 358 to 362.

ESTIMATED COST OF ENTRANCE LOCK.

Excavation 120,000 cubic yards @ $1.00	$120,000.00
Backfill. 75,000 cubic yards @ $ .40	30,000.00
Concrete Masonry 10,000 cubic yards @ $10.00	100,000.00
Reinforced Concrete 8,000 cubic yards @ $25.00	200,000.00
Reinforced Concrete piles 15,000 lineal feet @ $2.50	37,500.00
Steel Sheet Piling 50,000 square feet @ $1.60	80,000.00
Steel Gates 520,000 lbs. @ $ .10	52,000.00
Miscellaneous Steel 130,000 lbs. @ $ .20	26,000.00
Cofferdam, pumping, etc.	50,000.00
Contingencies	110,000.00
Total	$805,500.00

Lock Two A and Dam (upper end of Cut-off.) At the upper end of the cut-off channel, a dam and spillway will have to be built in connection with the lock, in order to keep the Big Muddy up to the required elevation, and to allow excess waters to go down the present channel.

At this point the north bank of the Muddy is a sheer cliff of rock, on a shelf of which is located the Missouri Pacific Railroad track. On the south side of the Muddy, the ground is lower and rises slowly to the bluff several hundred feet away. Rock underlies the river and also the south side, but is covered here with several feet of earth. In order to get room for the lock on the north side of the river without interfering with the railroad, it will be necessary to widen the river on the south side for a short distance below the lock.

The length of the dam will be approximately 325 feet and the cost is estimated as follows:

Earth excavation 6,000 cubic yards @ $ .75	$ 4,500.00
Rock excavation 3,200 cubic yards @ $2.50	8,000.00
Concrete masonry 13,200 cubic yards @ $10.00	132,000.00
Rolled embankment 40,000 cubic yards @ $ .75	30,000.00
Cofferdam, pumping, etc.	100,000.00
Contingencies	41,000.00
Total	$315,500.00

The cost of Lock Two-A is estimated as follows:

Earth excavation 1,000 cubic yards @ $1.00	$ 1,000.00
Rock excavation 1,500 cubic yards @ $2.50	3,750.00
Concrete masonry 8,200 cubic yards @ $10.00	82,000.00
Steel gates 430,000 lbs. @ $ .10	43,000.00
Miscellaneous steel and iron 110,000 lbs. @ $ .20	22,000.00
Cofferdam, pumping, etc.	100,000.00
Contingencies	38,000.00
Total	$289,750.00

Bridges and Waterways. On the cut-off as proposed, two railroads and three highways will be encountered, also a large drainage ditch and Kinkaid Creek.

South of Gorham, the canal would cross the Missouri Pacific Railroad. This crossing consists of two main tracks and one passing track. The passing track could be cut off before reaching the canal so that one two-track bridge would be necessary. The elevation of these tracks is about 365 while the high water in the pool is 362. Therefore, it would be necessary either to have a lift bridge, or to raise the tracks about seventeen feet to allow clearance for a stationary bridge. This could not be done except at great expense, as the railroad crosses the Illinois Central Railroad at grade only five hundred feet south, and enters the Gorham yard, seven tracks wide, only a few hundred feet to the north. Raising the grade would necessitate an overhead crossing of the Illinois Central and part raising of the yard tracks, as well as making an extremely heavy pull on the many freight trains using the Missouri Pacific tracks. For these reasons the plan is to install a lift bridge. In case of extreme high waters from the Mississippi, the tracks would be out of service, and in case the south levee along the canal is raised higher than the tracks, the gap at the railroad could be temporarily closed with sand bags, as is done on the Miami Conservancy work in Ohio.

The estimate of cost on this bridge would be as follows:

Span 75 feet—lift 20 feet.	
325,000 lbs. of steel and iron @ $0.10	$32,500.00
500 cubic yards concrete $10.00	5,000.00
Contingencies	9,500.00
Total	$47,000.00

The Illinois Central Railroad also would be crossed by the canal and, following the same arguments, a single track lift bridge is proposed, the cost of which would be as follows:

200,000 lbs. steel and iron @ $0.10	$20,000.00
400 cubic yards concrete @ $10.00	4,000.00
Contingencies	6,000.00
Total	$30,000.00

In addition to the two railroad bridges, two highway lift bridges would be necessary, estimated to cost about $17,000.00 each.

A third highway bridge can be eliminated by building a new road on the north side of the canal from the road leading from Gorham to Leo Rock, to the point where the road at present runs northerly near the Mississippi levee. This road could be placed on the right of way purchased for the channel, and the only expense would be for the earth work and drainage. It is about one mile long and the present road is a dirt road. The expense would be not over $5,000.00.

There are two streams crossing the line of the channel which are so low in grade that they cannot be turned into it, and so will have to pass under it. Kinkaid Creek is a very flashy stream, nearly dry in dry weather, but with a very heavy discharge in times of storms. To pass this under our channel will require a concrete and steel aqueduct seventy-five feet lengthwise of the channel and also seventy-five feet wide (the bottom width of our channel). A center pier would be necessary to sustain the great weight of water. The cost of this aqueduct is estimated as follows:

Structural steel 200 tons @ $100.00	$20,000.00
Reinforced concrete 1500 cubic yards @ $25.00	37,500.00
Plain concrete 350 cubic yards $10.00	3,500.00
Earth excavation 5000 cubic yards @ $1.00	5,000.00
Contingencies	10.000.00
Total	$76,000.00

The other stream crossing will be for the ditch of the Big Lake Drainage District. This also crosses at such a low grade that it could not enter the proposed canal.

It is proposed to place a large concrete barrel culvert here of about fifteen feet vertical and twenty foot horizontal diameter. The cost of this will be about $20,000.00.

This completes the proposed cut-off from the Mississippi to the Big Muddy. From this point the plan includes widening and deepening of the Big Muddy where necessary to obtain the required seventy-five foot bottom with slopes of one vertical to two horizontal. Cut-offs are proposed at the worst of the bends, and the estimate of cost is made both with and without the cut-offs. Two locks will be necessary, one raising the water from 362 elevation to 372 and another farther upstream with lift from 372 to 382. This will give an eight foot low water clearance all the way to the Fisher bridge, which is about two and one-half miles south of the Jefferson county line. At this point will be located a dam with necessary spillway and Tainter gates to raise the water to elevation 392.

This will be the outlet of the storage reservoir described later to supply water for navigation during dry weather periods.

The total length of route one is six and one-quarter miles on the cut-off and eighty-one and three-quarter miles from there to the reservoir.

The excavation necessary is as tabulated below.

Total excavation on cut-off—6.2 miles—883,000 cubic yards @ $ .40	$353,200

On the proposed improvement above the cut-off the river is divided into three sections by the locks and dams necessary to maintain a navigable depth. Calling the cut-off the first section or reach, the second section—from Lock Two A at the upper end of the cut-off, to Lock Three, is 58.76 miles in length of unimproved river. This includes the river to a point just below the mouth of Middle Fork. The excavation necessary to bring it to the required seventy-five foot bottom is 589,350 cubic yards. On this reach, desirable cut-offs can be made to eliminate the sharpest of the bends, which will cut out 4.06 miles with additional excavation (after deducting the excavation that would be necessary if these cut-offs were not made) of 239,635 cubic yards.

The third reach, from Lock Three to Lock Four, embraces 10.80 miles of unimproved stream with 779,770 cubic yards of excavation. Cut-offs may be made eliminating 1.07 miles of unimproved stream by an additional excavation of 50,890 cubic yards.

Reach Four extends from Lock Four to the upper end of the improved stream. It covers 12.20 miles of unimproved stream with an excavation of 1,008,080 cubic yards. On this reach, because of the extremely tortuous channel, 3.03 miles may be eliminated with an actual saving of 124,965 cubic yards.

These quantities together with the estimated cost of excavation are tabulated and given below:

EXCAVATION ON ROUTE 1

Reach	Without Cut-offs			Cut-offs.			Total improved stream.			Cost per mile of unimproved stream
	Miles.	Excav. Cubic yds.	Cost.	Miles.	Additional excavation.	Additional cost.	Miles.	Total excavation.	Total cost.	
1............	29.66	223,250	$ 89,300	23.45	659,750	$263,900	6.20	883,000	$353,200	$11,907
2.	58.76	589,350	235,740	4.06	239,635	95,854	54.70	828,985	331,594	5,643
3.	10.80	779,770	311,908	1.07	50,890	20,356	9.73	830,660	332,264	30,756
4............	12.20	1,008,080	403,232	3.03	Saving 124,965	49,986	8.90	883,115	353,246	28,954
Total...	111.42	2,600,450	$1,040,180	31.61	825,310	$330,124	79.53	3,425,760	$1,370,304	$12,298

Locks 3 and 4 and Dams. Locks 3 and 4 will be similar in lift and in cost. Each is 300 by 45 feet in inside dimensions with a lift of 10 feet.

The cost of each is as estimated below:

Excavation, 75,000 cubic yards @ $.60	$ 45 000.00
Concrete, 15,000 cubic yards @ $10.00	150,000.00
Sheet piling 275,000 square feet @ $.10	27,500.00
Foundation piling 50,000 lineal feet @ $.50	25,000.00
Cofferdam and pumping	25,000.00
Rip rap 4000 square yards @ $3.00	12,000.00
Steel and iron 350 tons @ $200.00	70,000.00
Contingencies	35,500.00
Total	$390,000.00

Right of Way and Flooded Area. Above the cut-off channel the elevation of the water will be 362 for 58.76 miles to Lock Three; 372 elevation for 10.8 miles to Lock Four and 382 for 12.2 miles to the reservoir dam. This will involve the flooding of some low ground where the river banks are low.

If levees were to be built in such places it would involve much difficulty in draining the adjacent lands, and possibly a number of pumping stations would be necessary to take care of the surface water outside the levees, with their maintenance and operation. Therefore, the flooded area has been estimated on each reach and cost of purchasing such lands at $30.00 per acre included in the estimate.

	Miles.	Flooded acres per mile.	Total acres flooded.	Cost.
Reach 2	58.76	50	2938	$88,140.00
Reach 3	10.80	45	486	14,580.00
Reach 4	12.20	40	488	14,640.00
Total	81.76	..	3912	$117,360.00

Added to this will be 188 acres necessary for right of way three hundred feet wide for the various cut-offs on reaches Two, Three and Four. This at $50. per acre will amount to $9,400.00.

Fisher Bridge North of Benton. Site of Reservoir Dam.

River in Reservoir Site One Mile South of Jefferson County Line.

Chapter IV.

IMPOUNDING RESERVOIR.

Because of the very limited flow of the Big Muddy during dry weather periods, an impounding reservoir will be necessary to hold back excess waters in wet periods, and store it for use later when the flow is small. For this purpose surveys were made above Fisher Bridge, which is about ten miles north of Benton. Just above this point Casey's Fork empties into the Big Muddy. The two streams diverge considerably above their junction, the Muddy coming from the north and northwest and Casey's Fork from the northeast. The dam was located at Fisher's Bridge and with a crest elevation of 392, with high water elevation in reservoir at 394 in extreme floods.

With the crest elevation of 392, the flooded area will be about four miles in length, of which about 1.5 miles will be in Jefferson county. The width at the dam will be about three-quarters of a mile and at the county line about a mile.

The area on the 392 level is about 2400 acres with a volume of 305,000,000 cubic feet, or 7000 acre feet. On the basis of a flow of 75 cubic feet per second, this means a 47 day supply. With the water reaching the channel from other tributaries below, this would be sufficient to maintain navigation at all times.

The land included in this reservoir is mostly low and covered with timber. Some of it, however, is now under cultivation. Most of it would have a very low value, but with the clearing of timber and brush, a value for estimating is assumed at $50.00 per acre. With 2400 acres this would amount to $120,000.

The reservoir dam will be 4900 feet in length with top 15 feet wide, with upper slope of three to one and lower slope two to one. The Tainter gates and concrete part will be 120 feet in length, leaving 4780 feet of earthen dam. The amount of fill required is 50,100 cubic yards. Estimated at fifty cents per cubic yard, this amounts to $25,050.00. The estimate on concrete work and gates is as follows:

90,000 lbs. of steel @ $ .10	$ 9,000.00
2,500 cubic yards concrete @ $10	25,000.00
1,250 lineal feet of piling @ $ .75	9,375.00
2,000 cubic yards excavation @ $1.00	2,000.00
3,600 square feet sheet piling @ $1.00	3,600.00
Cofferdam and pumping	5,000.00
Contingencies	1,025.00
	$ 55,000.00
Also for raising roads and bridges in the reservoir and leaving necessary openings	$ 25,000.00

Resume of Cost on Route One. Summing up the various items of cost given on preceding pages, and adding the cost of storage reservoir as shown in Chapter 5, we find the total cost of improving the river and making the cut-off from the Mississippi to Lock Two A to be as follows:

Entrance Lock (Lock One A)	$ 805,500.00
Lock Two A—upper end of cut-off	289,750.00
Dam at Lock Two A	315,500.00
Excavation on cut-off	353,200.00
Embankment on cut-off	37,500.00
Right of way on cut-off	17,000.00
Missouri Pacific two track lift bridge	47,000.00
Illinois Central one track lift bridge	30,000.00
Two highway lift bridges	34,000.00
Kinkaid Creek aqueduct	76,000.00
Drainage ditch culvert	20,000.00
New Highway to avoid bridge	5,000.00
Contingencies on cut-off	100,000.00
Total for cut-off	$2,130,450.00
Lock Three and dam	$ 390,000.00
Lock Four and dam	390,000.00
Flooded area 3,912 acres @ $30.00	117,360.00
Excavation above Lock Two A	1.017,104.00
Reservoir dam, spillway and gates	80,050.00
Reservoir land	120,000.00
Highway and road damages	25,000.00
Right of way for cut-offs	9.400.00
Total estimate route one	$4,279,364.00

This makes a total cost per mile for the length of the unimproved stream (111.42 miles) of $38,407.00, and a total cost per mile of the stream as improved (79.53) miles of $53,809.00.

Looking Downstream From Fisher Bridge.

Drift Collected in Big Muddy Near Rend City Bridge.

CHAPTER V.

ROUTE TWO—ALL RIVER ROUTE.

By this route the cut-off from Sand Ridge to the Mississippi is not used, and the improvement would extend from the mouth of the Big Muddy to the same upper terminus at the reservoir. By the use of this route about twenty-four miles would be added to the length of Route One but the expensive entrance lock on that route would be replaced by one of lower lift and less expensive. Also the large amount of excavation on the cut-off would be avoided.

By Route Two the entrance lock would be placed up the river between the Illinois Central and Missouri Pacific railroads. No changes of railroad bridges would be necessary as they are now on a level high enough to permit a good clearance on the waterway.

Some highway bridges may have to be raised on the lower stretch but not involving a heavy cost.

Lock One, entrance lock, will raise the water from the Mississippi stage to 345 elevation.

Lock Two, located about a half mile east of the Illinois Central main line between DeSoto and Carbondale, raises the level from elevation 345 to 362. Beyond that point the improvement would be the same as for Route One in all respects.

Lock One will have its mitersill at 319 elevation to allow for extremely low water in the Mississippi. The cost of this lock will be considerably cheaper than the entrance lock or Route One as the lift is fifteen feet less.

This and the dam with it are estimated to cost complete $410,000.00.

Lock Two, with a seventeen foot lift, is similar to Locks Three and Four, described under Route One, except for seven feet higher lift. It is estimated to cost $460,000. Locks Three and Four, as stated above, are the same as on Route One and are estimated at $390,000 each.

Excavation and cut-offs. On Reach One, from the Mississippi to Lock Two, by the unimproved stream, the distance is 53.75 miles and the excavation required for the same channel width as Route One, is 223,250 cubic yards. By the further excavation of 198,380 cubic yards, 2.30 miles of channel may be saved on cut-offs.

Reach Two covers 34.67 miles of unimproved channel, and requires 589,350 cubic yards of excavation. 4.06 miles may be eliminated by desirable cut-offs which will require 239,635 cubic yards more excavation.

Reaches three and four are the same for both routes and are described under Route One.

The total length of unimproved channel by Route Two is 111.42 miles and the new length if cut-offs are made would be 100.69 miles.

These quantities, together with the estimated cost of excavation, are tabulated and given below.

EXCAVATION ON ROUTE 2

Reach	Without Cut-offs.			Cut-offs.			Total improved stream.			Cost per mile of unimproved stream.
	Miles.	Excav. Cubic yds.	Cost.	Miles.	Additional Excavation	Additional cost.	Miles.	Total excavation.	Total cost.	
1............	53.75	223,250	$ 89,300	2.30	198,380	$79,352	51.45	421,630	$168,652	$ 3,138
2............	34.67	589,350	235,740	4.06	239,635	95,854	30.61	828,985	331,594	9,564
3............	10.80	779.770	311.908	1.07	50,890	20,356	9.73	830,660	332,264	30,765
4............	12.20	1,008,080	403,232	3.30	Saving 124,965	49,986	8.90	873,115	353.246	28,955
Total....	111.42	2,600,450	$1,040,180	10.73	363,940	$145,576	100.69	2,964.390	$1,185,756	$10,642

Flooded Area. The flooded area on the first two reaches of Route Two will be much less than on Route One and will also be less in value because it is largely on the slope of the bank and not usable for cultivation. It is estimated as follows:

Reach 1	53.75 miles	538 acres	@ $20.00	$10,760.00
Reach 2	34.67 miles	693 acres	@ $20.00	13,860.00
Reach 3	10.80 miles	486 acres	@ $30.00	14,580.00
Reach 4	12.20 miles	488 acres	@ $30.00	14,640.00
Total		2205 acres		$53,840.00

Right of way will also have to be purchased on the various cut-offs which should be 300 feet wide. For this 214 acres will be necessary which, at $50.00 per acre, will amount to $10,700.

Reservoir. The improvement on the river above Lock Three and the reservoir are the same as on Route One so the description will not be repeated.

Resume of Cost. The estimated cost of Route Two, as shown above, is summed up as follows:

Lock One	$ 410,000.00
Lock Two	460,000.00
Lock Three	390,000.00
Lock Four	390,000.00
Reach 1—Excavation 421630 cubic yards @ $.40	168,652.00
Reach 2—Excavation 828985 cubic yards @ .40	331,594.00
Reach 3—Excavation 830660 cubic yards @ .40	332,264.00
Reach 4—Excavation 873115 cubic yards @ .40	353,246.00
Right of way for cut-offs 214 acres	10,700.00
Flooded land 1,231 acres @ $20.00	24,620.00
Flooded land 974 acres @ $30.00	29,220.00
Reservoir dam, spillway and gates	80,050.00
Reservoir land	120,000.00
Highway and road damages in reservoir	25,000.00
Bridges and roads raised on channel	50,000.00
Total	$3,175,346.00

This makes a total cost per mile for the unimproved stream (111.42 miles) of $28,499.00 and a total cost per mile of the improved stream of $31,536.00.

Railroad Bridge Southeast of Christopher.

Railroad Bridge West of Benton.

Chapter VI.

ADVANTAGES AND DISADVANTAGES—COMPARISON OF ROUTES.

The great advantage of Route One is the saving of time and distance. Route One has a length of 6.25 miles from the Big Muddy to the Mississippi. From the same point on the Big Muddy, Route Two has a length of 29.7 miles by the present stream or 28 miles when the proposed cut-offs have been made. This is a difference of distance in favor of Route One of 21.75 miles. The cost of barging coal on other streams is at present very little over one mill per ton-mile. Assuming 1½ mills per ton-mile for our rate, and the total tonnage per annum at 5,000,000, 10,000,000 and 15,000,000 tons, we have the following tabulation to show the saving per day and per year.

COMPARISON OF COST OF TRANSPORTING COAL BY ROUTES ONE AND TWO.

Item.	5 million tons per annum.	10 million tons per annum.	15 million tons per annum.
Tons per day (365 days)	13,700	27,400	41,100
Barge loads per day 750 tons each	19	37	55
Cost of hauling per ton mile @ $.0015	$20.55	$41.10	$61.65
Cost of hauling by Route One (cut-off) per day (6¼ miles)	128.44	256.88	385.32
Cost of hauling by Route Two (river) per day (28 miles)	575.40	1,150.80	1,726.20
Saving by canal per day	446.96	893.92	1,340.88
Saving by canal per year (365 days)	$163,140.40	$326,280.80	$489,421.20

The cost for barging as given above, $ .0015 per ton-mile, includes no charge for loading or unloading, but does include that of barging back upstream empty.

Another advantage of Route One is that most of the coal shipments will be for points up the Mississippi; and for such traffic, Route One would be still shorter by the distance from the mouth of the Muddy to the mouth of the cut-off.

For coal destined to the south this would not be true.

Against Route One would be primarily the much greater first cost. The cut-off channel on Route One would be almost entirely additional to the cost of Route Two. Furthermore, the four lift bridges on the cut-off would be a permanent source of expense both for maintenance and operation. Not only would these bridges be a constant expense, but they also seriously impede the immense freight traffic on the Missouri Pacific Railroad especially. On this line both the Missouri Pacific and the Cotton Belt roads carry their freight from the south and southwest via the Thebes bridge to St. Louis. This traffic and the water traffic would both be subject to numerous delays by the bridge being either opened or closed as the case may be. Again, Route Two being seventeen feet lower in grade on reaches one and two would subject much less land to overflow than Route One. Less changes would consequently be necessary on highways and bridges. Less trouble would be encountered in caring for incoming streams and tributaries. More room would be given within the channel banks for the occasional high water from heavy rains.

Chapter VII.

CONCLUSIONS AND RECOMMENDATIONS.

The Big Muddy can be improved for barge navigation at a cost indicated in this report. The principal product of the community through which the river flows is coal mined on or near the river banks. Also considerable business has developed lately at Murphysboro in the manufacture of paving brick, a large portion of which would be transported by water. The four counties in the Big Muddy valley produced in 1922 thirty-four per cent. of the total coal mined in the State of Illinois. This had increased from a total of twenty-one per cent. in 1910. There are at present forty-four mines within range of five miles from the Big Muddy, and, if the improvement is made, many new mines might be opened nearer the river. If the Big Muddy is improved, this coal could be transported all the way by water to such points as Chicago, St. Louis, New Orleans, Minneapolis and other Mississippi river points. Some return cargo would be found, principally steel and lumber. For the reasons set forth in Chapter 6, Route No. 2 is shown to be the most feasible.

There are periods of the year when the natural flow of the stream is not sufficient to supply water for a heavy traffic. The low water flow can be supplemented by the creation of reservoirs at the head waters of the stream.

Respectfully submitted,

W. G. Potter,
Engineer, Division of Waterways.

STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS & BUILDINGS
DIVISION OF WATERWAYS

LOCATION MAP

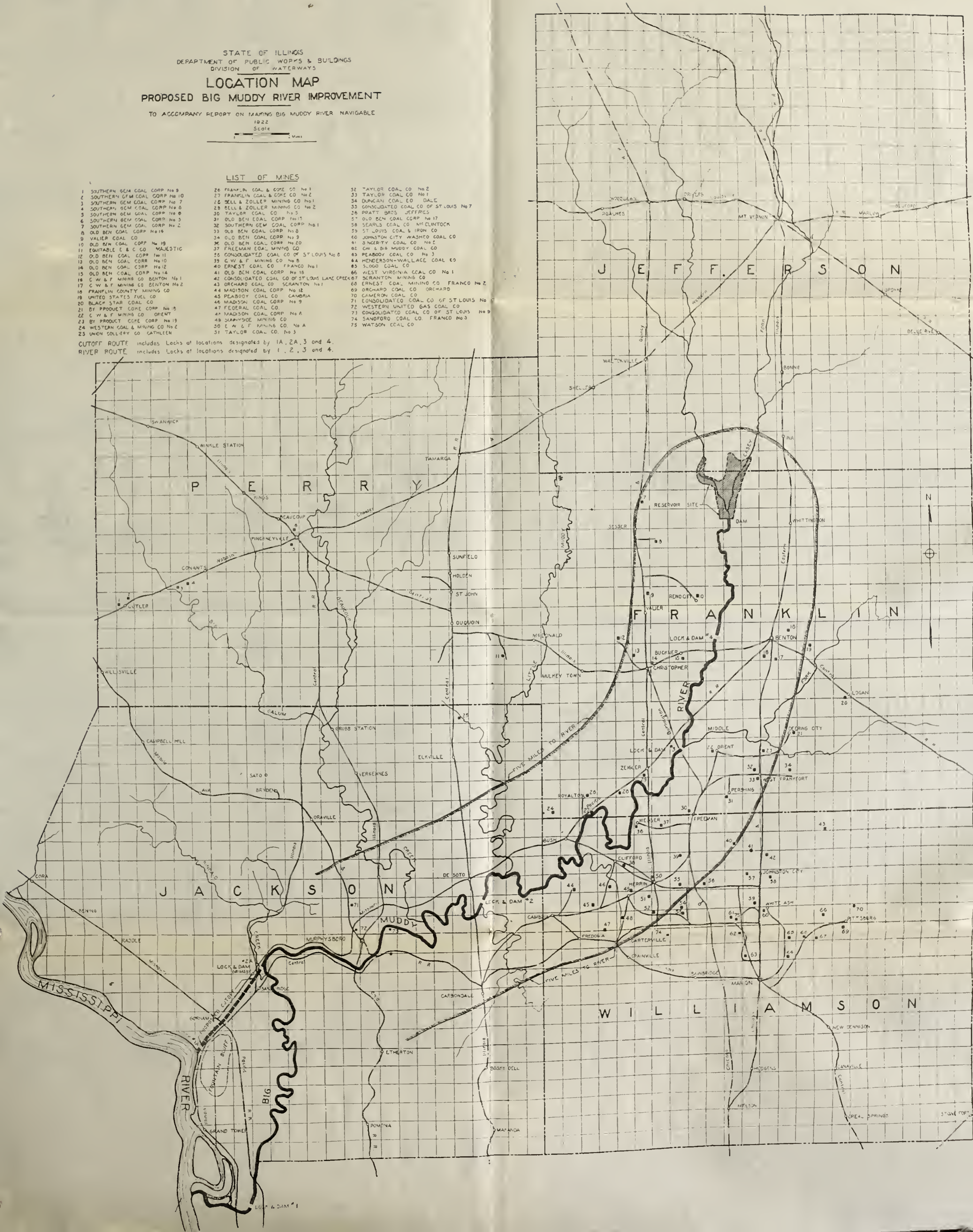
PROPOSED BIG MUDDY RIVER IMPROVEMENT

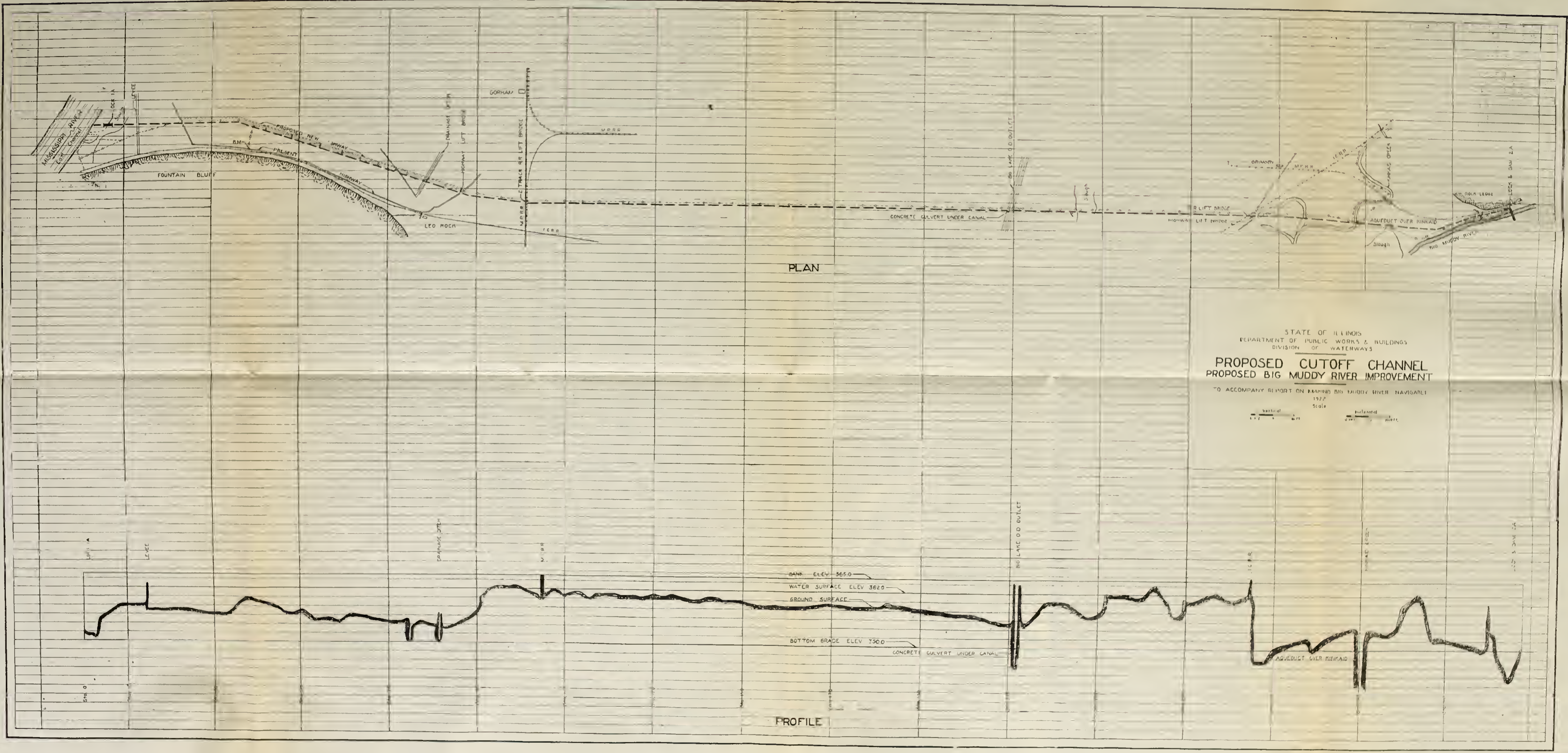
TO ACCOMPANY REPORT ON MAKING BIG MUDDY RIVER NAVIGABLE
1922
Scale
2 Miles

LIST OF MINES

1	SOUTHERN GEM COAL CORP No 9
2	SOUTHERN GEM COAL CORP No 10
3	SOUTHERN GEM COAL CORP No 7
4	SOUTHERN GEM COAL CORP No 8
5	SOUTHERN GEM COAL CORP No 6
6	SOUTHERN GEM COAL CORP No 3
7	SOUTHERN GEM COAL CORP No 2
8	OLD BEN COAL CORP No 16
9	VALIER COAL CO
10	OLD BEN COAL CORP No 19
11	EQUITABLE C & C CO MAJESTIC
12	OLD BEN COAL CORP No 11
13	OLD BEN COAL CORP No 10
14	OLD BEN COAL CORP No 12
15	OLD BEN COAL CORP No 14
16	C W & F MINING CO BENTON No 1
17	C W & F MINING CO BENTON No 2
18	FRANKLIN COUNTY MINING CO
19	UNITED STATES FUEL CO
20	BLACK STAR COAL CO
21	BY PRODUCT COKE CORP No 18
22	C W & F MINING CO ORIENT
23	BY PRODUCT COKE CORP No 19
24	WESTERN COAL & MINING CO No 2
25	UNION COLLIERY CO CATHLEEN
26	FRANKLIN COAL & COKE CO No 1
27	FRANKLIN COAL & COKE CO No 2
28	BELL & ZOLLER MINING CO No 1
29	BELL & ZOLLER MINING CO No 2
30	TAYLOR COAL CO No 5
31	OLD BEN COAL CORP No 15
32	SOUTHERN GEM COAL CORP No 1
33	OLD BEN COAL CORP No 8
34	OLD BEN COAL CORP No 9
36	OLD BEN COAL CORP No 20
37	FREEMAN COAL MINING CO
38	CONSOLIDATED COAL CO OF ST LOUIS No 8
39	C W & F MINING CO No 8
40	ERNEST COAL CO FRANCO No 1
41	OLD BEN COAL CORP No 18
42	CONSOLIDATED COAL CO OF ST LOUIS LAKE CREEK
43	ORCHARD COAL CO SCRANTON No 1
44	MADISON COAL CORP No 12
45	PEABODY COAL CO CAMBRIA
46	MADISON COAL CORP No 9
47	FEDERAL COAL CO.
48	MADISON COAL CORP No 8
49	SUNNYSIDE MINING CO
50	C W & F MINING CO. No A
51	TAYLOR COAL CO. No 3
52	TAYLOR COAL CO No 2
53	TAYLOR COAL CO No 1
54	DUNCAN COAL CO DALE
55	CONSOLIDATED COAL CO OF ST LOUIS No 7
56	PRATT BROS JEFFRIES
57	OLD BEN COAL CORP No 17
58	SEARLS COAL CO McCLINTOCK
59	ST LOUIS COAL & IRON CO
60	JOHNSTON CITY WASHED COAL CO
61	SINCERITY COAL CO No 2
62	CHI & BIG MUDDY COAL CO
63	PEABODY COAL CO No 3
64	HENDERSON-WALLACE COAL CO
65	SLOGO COAL CO
66	WEST VIRGINIA COAL CO No 1
67	SCRANTON MINING CO
68	ERNEST COAL MINING CO FRANCO No 2
69	ORCHARD COAL CO ORCHARD
70	CAMERON COAL CO
71	CONSOLIDATED COAL CO OF ST LOUIS No
72	WESTERN UNITED GAS COAL CO
73	CONSOLIDATED COAL CO OF ST LOUIS No 9
74	SANDFORD COAL CO. FRANCO No 3
75	WATSON COAL CO

CUTOFF ROUTE includes Locks at locations designated by 1A, 2A, 3 and 4.
RIVER ROUTE includes Locks at locations designated by 1, 2, 3 and 4.

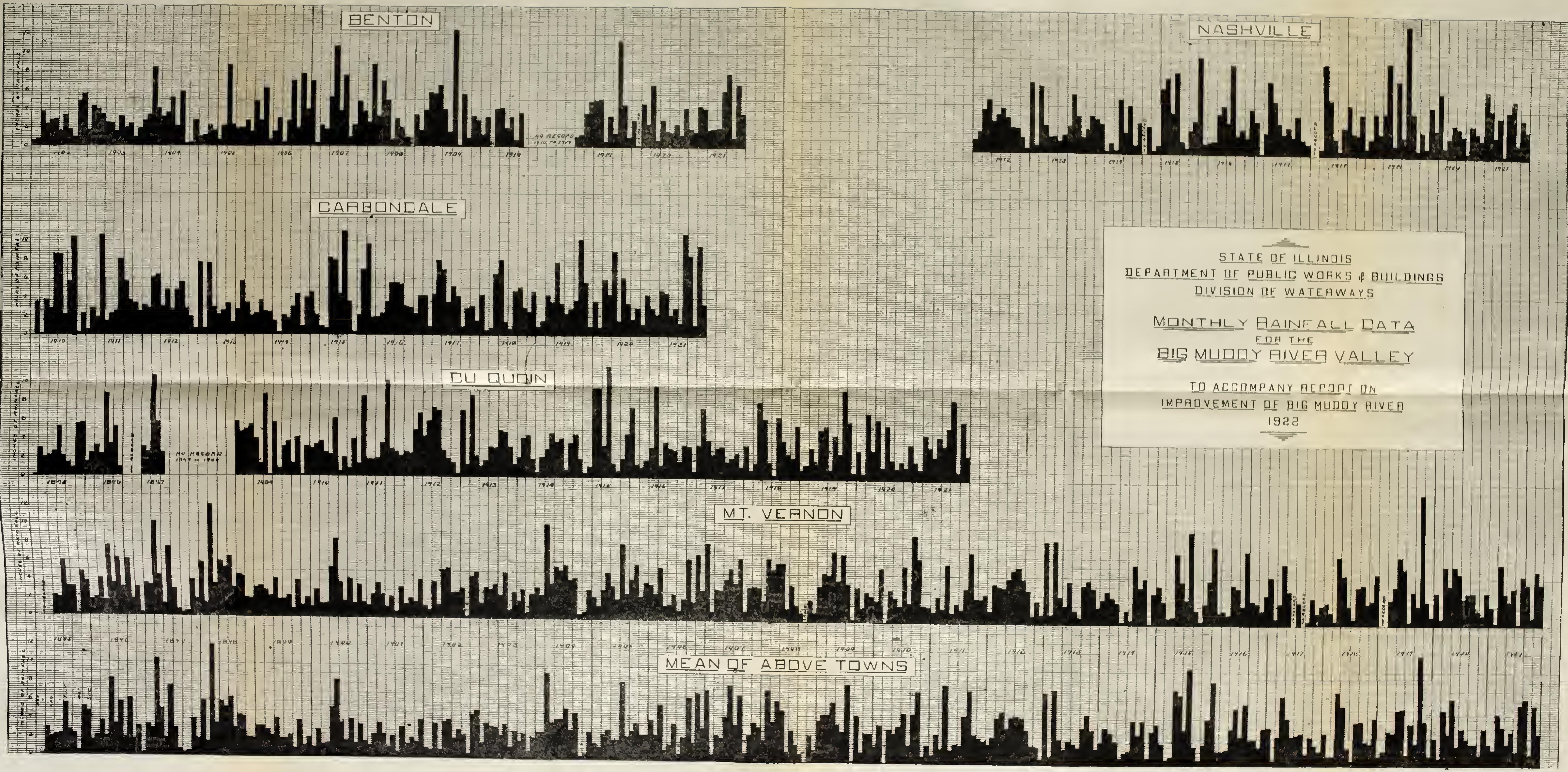




STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS & BUILDINGS
DIVISION OF WATERWAYS

PROPOSED CUTOFF CHANNEL
PROPOSED BIG MUDDY RIVER IMPROVEMENT

TO ACCOMPANY REPORT ON MAKING BIG MUDDY RIVER NAVIGABLE
1922
Scale



STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS & BUILDINGS
DIVISION OF WATERWAYS

MONTHLY RAINFALL DATA
FOR THE
BIG MUDDY RIVER VALLEY

TO ACCOMPANY REPORT ON
IMPROVEMENT OF BIG MUDDY RIVER
1922

DIVISION OF WATERWAYS.

WM. L. SACKETT, *Superintendent.*

THE ILLINOIS WATERWAY.

In addition to the work of developing plans for the Illinois Waterway, the Fifty-second General Assembly enacted laws, the execution of which devolves upon the Division of Waterways and involves technical engineering supervision.

Following is the report of M. G. Barnes, Chief Engineer of the division, covering the engineering work of the division to June 30:

ENGINEERING REPORT UPON THE ILLINOIS WATERWAY.

By M. G. BARNES, *Chief Engineer, Division of Waterways.*

During the fiscal year just closed several engineering activities have been added to the duties of the Division of Waterways. These new duties have taken considerable time of the Chief Engineer and several of his principal assistants. The department is required to pass on the flood discharge capacity of all bridges to be built within the State, and inasmuch as the State Highway Department and the various counties are actively engaged in construction of new roads, the department is called upon to advise on the location and capacity of many bridges throughout the State. This requires a large amount of field and office inspection and investigation.

The last Legislature passed an Act (Laws of Illinois, 1921, p. 184) relating to the establishment of an industrial harbor at Lake Calumet, the plans of which must be approved by this department. This work has been given consideration by the engineers of this office in line with regular duties.

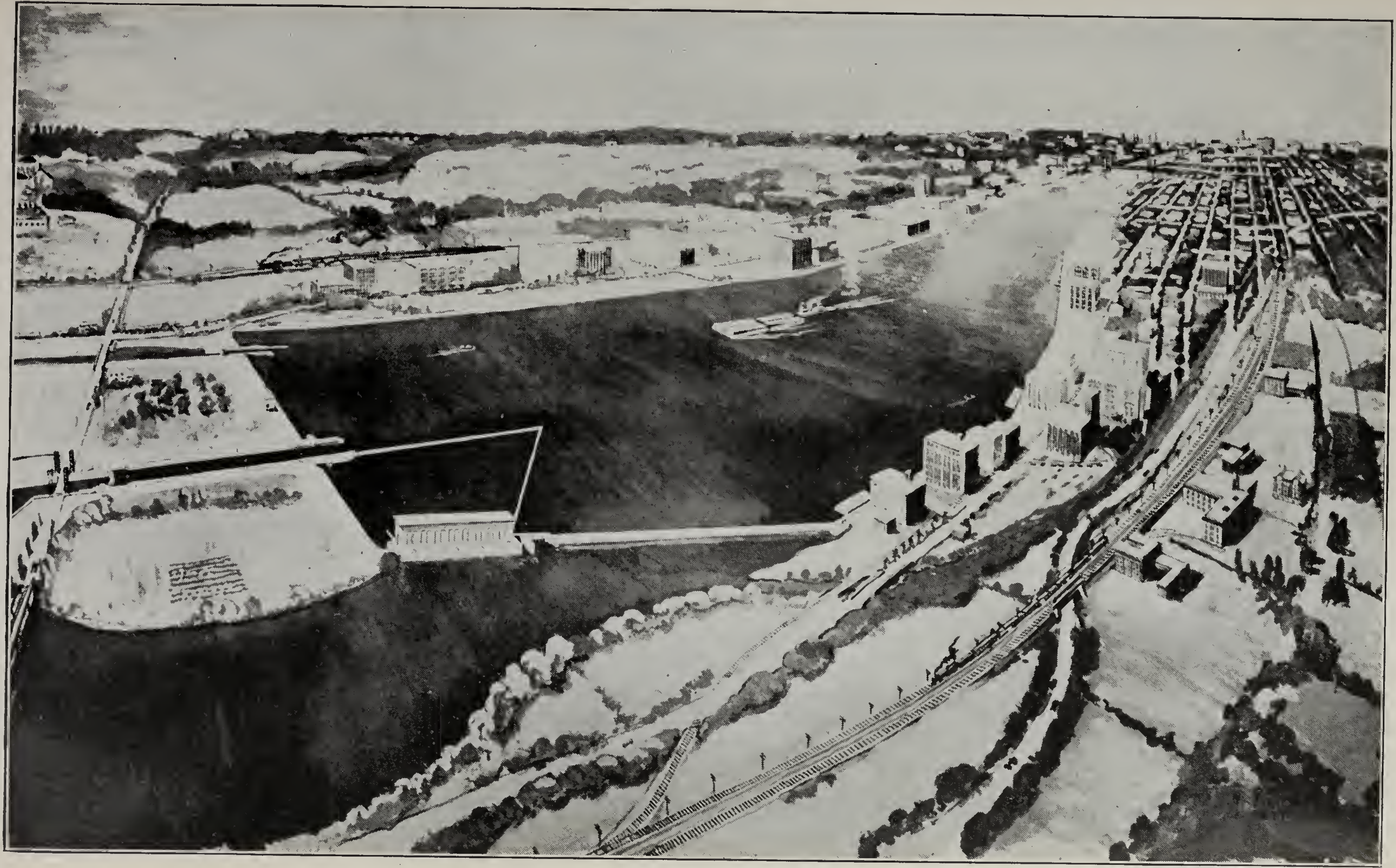
Concurrently with the Legislature of Indiana, the last Legislature of Illinois passed an Act creating an Inter-State Harbor Commission to report on the advisability of establishing a harbor on the State line at Wolf Lake. The Chief Engineer of this department has given consideration to that problem and especially as to its bearing on the construction of the Illinois Waterway. Some of the large corporations are showing considerable interest in the establishment of harbors and other water shipping facilities in the vicinity of Wolf Lake and other points at or near the State line. The steel interests and other large users of coal are desirous that adequate terminal facilities shall be provided and that the lake be connected by an adequate waterway for barge transportation with the Illinois and Mississippi Rivers. Experience of the steel interests in shipping on the Ohio shows that their products may be transported over the rivers of the Mississippi Valley more cheaply than by rail, and inasmuch as there will be but five locks between Chicago and New Orleans via the Illinois Waterway as against more than ten times as many on the Ohio River, the steel interests are having their attention drawn to the advantages of the Chicago District as against Pittsburgh for the distribution throughout the Central West and for export business through the port of New Orleans. Every effort should be made to extend the Illinois Waterway through the Sag Channel and provide an adequate terminal near Lake Michigan. If this is done, millions of tons of coal, steel, sand and other heavy products will find transportation over the Illinois Waterway and the steel and cement mills around the head of Lake Michigan will greatly increase in importance.

Another duty added to this division by the last Legislature is supervision of plans for drainage districts. Experience during the floods of March and April of this year indicates that it is high time some general supervision is exercised over the location and design of levee districts along our important streams. The commissioners and attorneys representing districts have not in all cases co-operated whole-heartedly in the execution of this new law; some attorneys holding that the law is inoperative and have so advised the commissioners. In the past, levees have been located and designed with little reference to the effect they would have on adjoining property. There has been no general supervision, each owner or community of owners doing his work so as to protect himself against flood with little thought or consideration of the general welfare of those similarly situated along the same stream. As this work has progressed it is found that the levees built have not only damaged others but have resulted in higher stages of water than existed previous to the creation of these levee districts and higher even than anticipated by their engineers, so that they find they are not protected from floods as they had expected. Much valuable land yet remains to be protected or reclaimed and numerous districts are anticipating further land reclamation. This work should not be allowed to progress in a haphazard manner as in the past, but should be given more rigid supervision by some State authority, preferably the Division of Waterways. More adequate discharge capacity should be given to the streams and compensating works of some sort provided where the flood plain is encroached upon; in fact, the Legislature might well consider providing compensating works as a relief for encroachments already made. The effect of levee construction on the Illinois River has been treated by Alvord & Burdick in their report to this department under the title of The Illinois River and Its Bottôm Lands. This was also reviewed by the writer and published elsewhere in this report.

Engineers for the work covered by the duties above outlined have been drawn largely from the regular office force of the Illinois Waterway, and the designing force reduced correspondingly. The organization has been further reduced by the resignation of some of its members, so that but a skeleton organization remains.

It is well known that the amount of water diverted from Lake Michigan by the Chicago Sanitary District is in excess of the amount permitted by the Secretary of War, although it is no more than required by the State of Illinois for the dilution of the sewage. Controversy has arisen with certain officials at Washington regarding this excess diversion, and the Division of Waterways together with the trustees of the Sanitary District have endeavored during the past year to find some means of settling this controversy. The chief engineer of this department has made several trips to Washington and devoted a great deal of time and study to the problem in an effort to find some solution. A bill has been drawn providing for a diversion of 10,000 cubic feet per second from Lake Michigan, which will be introduced in Congress during the next session. It is hoped that sufficient support can be obtained to pass this measure.

Extended study and revision of plans have been made during the past fiscal year. The principal new work on plans has been confined to the location through Joliet. At the lower limits of the city there will be constructed a lock and dam having a lift of 31 feet. This will raise water above the banks of the river through the city, requiring the construction of retaining walls on both sides to confine the water to the river channel. The work is further complicated by the fact that the sewers of Joliet empty into the river at various points requiring interception and leading to the pool below the proposed dam and lock knows as Brandon Road lock and dam. Various studies and tentative locations for these structures have been made, resulting in a final location of the lock just above Brandon Road with the proposed power house to the left of the upper end of the lock. The intercepting sewers have been located within the concrete retaining walls above mentioned. This probably provides the most economical location for the sewers and provides cut-off for any water that might find its way under the walls. It is essen-



Brandon Road Lock, Dam and Power House (at Joliet, Ill.) as they will look when completed.

tial that positive means of discharging the floods of the DesPlaines River shall be provided so that no damage shall be done to the property lying below the new water surface. To this end a long portion of the retaining wall on the left bank has been designed as an overflow weir. In addition several gates have been designed to be installed at the lower end of the retaining wall to provide additional discharge capacity. In case some of these gates are jammed or otherwise out of commission, the spillway will still carry off flood waters without raising the water to an undue height. Moreover there still remains the gates in the lock chamber that will discharge a large amount of water and the power house which if in operation will discharge more water than the sulice gates. With these various openings, it does not seem that there is a chance of flooding low lands or creating other damages at flood times. The new construction will raise the low water through the city of Joliet from ten to nearly thirty feet. This will necessitate the reconstruction of all bridges through the city and the provision for movable spans. Studies are now being made of various types of bridges that would lend themselves to the locations along the waterway. Owing to the necessity of keeping the street grades as flat as possible it will be necessary to place the bridges close to the water surface and operate them for the passage of all boats. This will require bridges that can be operated quickly. It is found that the waterway can be located through the city and the bridges so constructed as to do but little damage to streets and adjoining property.

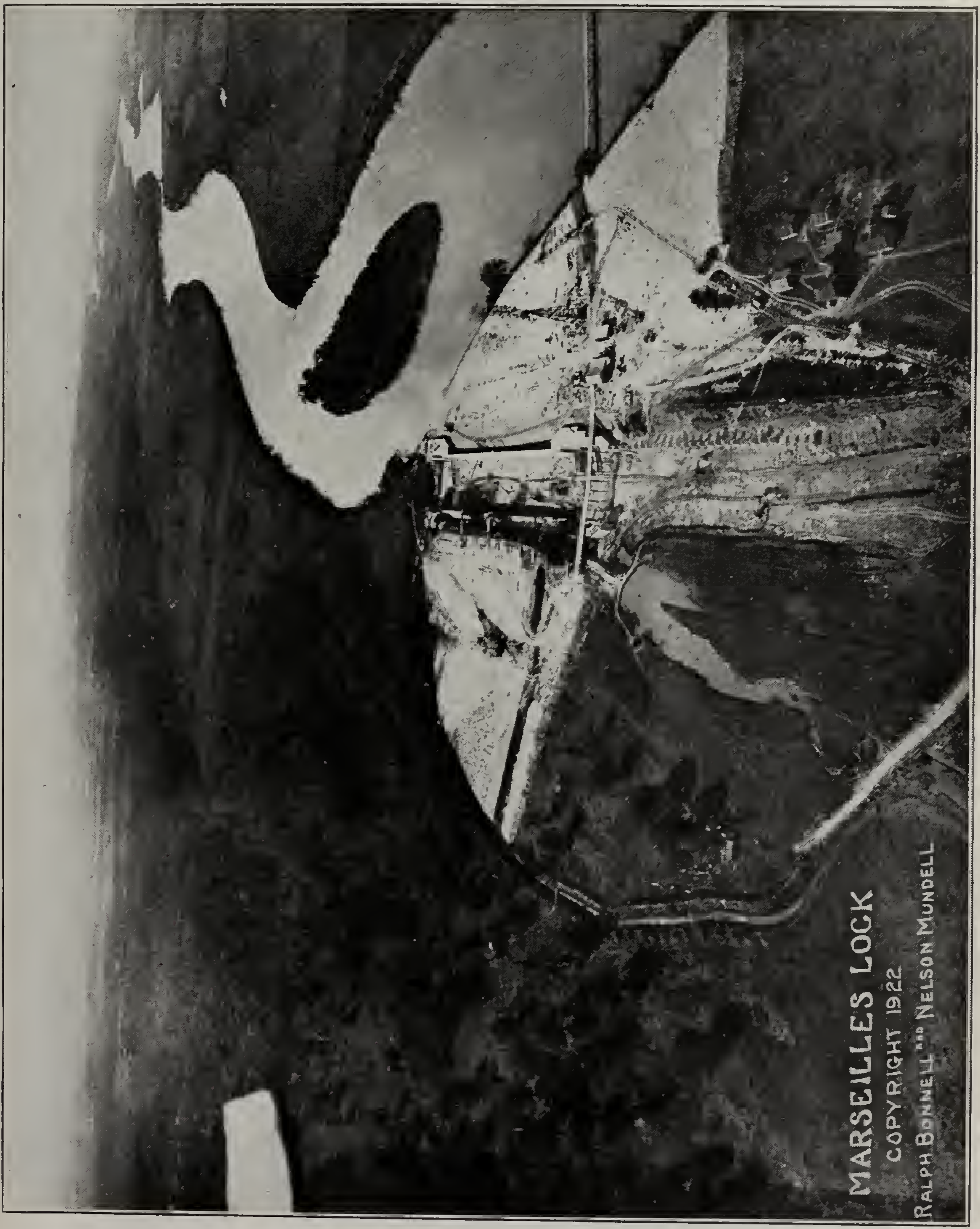
WATER POWER.

There will be four water power plants created as a by-product incident to the construction of this waterway. These will be located at Brandon Road. Dresden Island, Marseilles and Starved Rock. Together there will be a maximum development of upwards of 75,000 horse power. Studies of the designs of the power plants are being continued as time permits. Water power is increasing in importance and value and the State will find that it is possessed of valuable water power rights that should be developed at the earliest possible date. These power plants should be installed by the State and leased for a long term of years, lessee to maintain and operate plant. This will relieve the State of any operation and maintenance complications and the employment of an operating crew. and permit the lessees to operate the plant at his will. Such contracts usually result in the highest net revenue to the owner of the plant. The State has negotiated a permit through the Federal Water Power Commission for the construction of these plants and should lose no time in their design and construction. The revenue that may be obtained from these plants will be sufficient to pay a handsome rate of interest on the total cost of power construction.

SURVEYING AND MAPPING.

A survey party under the direction of Assistant Engineer M. C. Lewis worked in the Ottawa Division from July 7, 1921, to June 30. 1922. During this time the territory along the Illinois River from a point about three quarters of a mile above or eastward from the site of proposed Starved Rock Lock and Dam to the upper end of the Starved Rock Reservoir at Bells Island. and from the present water power dam at Marseilles to the vicinity of the town of Seneca has been covered. Land lines were carefully located so that future descriptions of land referred thereto could be successfully defended in court if necessary. Contours of the proposed pool levels and of an appropriation line were staked on the ground and later located together and coincident with the general topographic features of the land in the immediate vicinity. The topography was taken with a view to developing all natural drainage lines, lines of cultivation especially on the numerous islands and the low foreshore where many sloughs and tracts of waste land are found, lines of divisions of ownership, farm buildings which lie close to the proposed flooded area, and public highways in the immediate vicinity.

All topography was taken by the stadia method and notes therefrom have been computed and kept fairly well up to progress of the field party by office work of the field party at odd times and by the Division Engineer and the stenographer. Computations necessary for the proper platting of the field notes have been completed covering the area from the Starved Rock site to the east city limits of Ottawa and all manuscript maps have been platted and inked. One map, on an enlarged scale, covering the outlet of what is locally known as the "County Farm drains" was platted and traced for special study. Three maps covering the territory bordering on the city of Ottawa were also traced.



(Marseilles Lock (view from aeroplane).

All survey work and all map platting has been done with the idea of computing descriptions of areas to be appropriated without the necessity of the survey party returning to the field for re-surveys except possibly in a few particular cases.

CONTRACT WORK.

No contracts have been let for construction work during the year, Contract No. 1, let to Green & Sons Co., of Chicago, under bids received October 18, 1920, being the only one under construction.

CONTRACT NO. 1.

The execution of this contract has been under the field supervision of J. B. Bassett, Division Engineer, and R. S. Heath, Resident Engineer, in local charge of the work for the State. The work under this contract has progressed satisfactorily. While the contractor is behind schedule time, the work seems to be well in hand, and inasmuch as other contract work has not been let and this work will not be required by the State at the completion of the contract time, there seems to be no adequate reason for requiring the contractor to make better progress. The work consisted principally of pit and east approach excavation which is about 70 per cent complete and of concrete construction which is about 30 per cent complete. The former could have been entirely completed but the contractor preferred to delay a portion of the pit excavation so that the waste could be deposited as backfilling behind the north wall to avoid the necessity of rehandling. Progress was considerably increased during the last two months of the year but the completion of the work within the specified time is doubtful.

Clearing.—All clearing was completed during the year ending June, 30, 1921.

Fencing.—Fencing was completed except minor retaining and straightening during 1921.

Excavation.—Excavation of the lock pit was carried on for nine months of the year by a 70-ton Bucyrus shovel and for about six and one-half months by a small rotary shovel. The latter was used largely for trimming and casting over blasted material from points more or less inaccessible for the larger shovel.

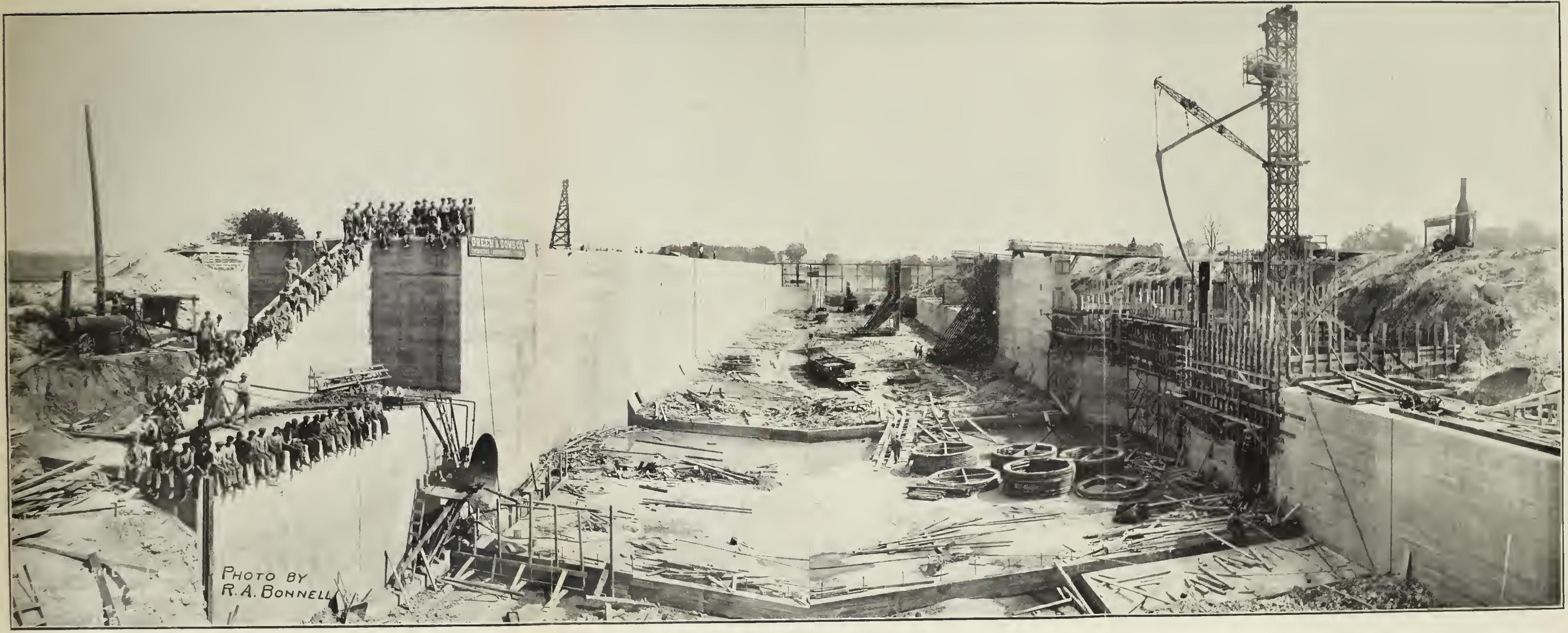
About 87,000 cu. yds. of material were excavated during the year. The waste was handled by dump cars and was deposited on the spoil area on the north side of the lock.

Drilling for blasting was done by a well drill outfit except for incidental trimming on bottom and sides where jack hammers were used.

Plant.—The principal plant activity during the year was the completion of the concrete receiving plant and appurtenances. Machinery was installed, auto trucks fitted with special concrete dumping boxes were provided and sheds built for housing same, hoppers and spouting for conveying concrete from the edge of the pit to the forms were purchased and installed, and one elevating tower with attached chuting appliances was purchased and erected for use in the large wall sections around the gate anchorages.

A trestle was built across the head bay of the lock at an elevation a few feet above the finished wall height for conveying concrete to the south wall by motor trucks.

In January the trestle bridge across the Illinois River was threatened by ice and was removed by the use of the cableway. The parts were numbered and piled on either shore for easy replacing. In March the bridge was replaced but was washed out on April 11 by high water which rose on the 12th to an elevation of 470.6 N. Y. M. T. or about three feet above the general level of the deck of the bridge. All of the deck and stringers and about one third of the bents were salvaged. The bridge was again replaced a few days later after the stage of water had lowered. During the high water interval most of the crew were placed on the bridge to handle the floating debris and prevent its forming a dam against the decking. During this operation Nick Stoich, a laborer, fell from the bridge and was drowned. His body was recovered a few weeks later in the river below Ottawa. In addition to the above, maintenance of all plants, tracks and other equipment was under way



Marseilles Lock During Construction.

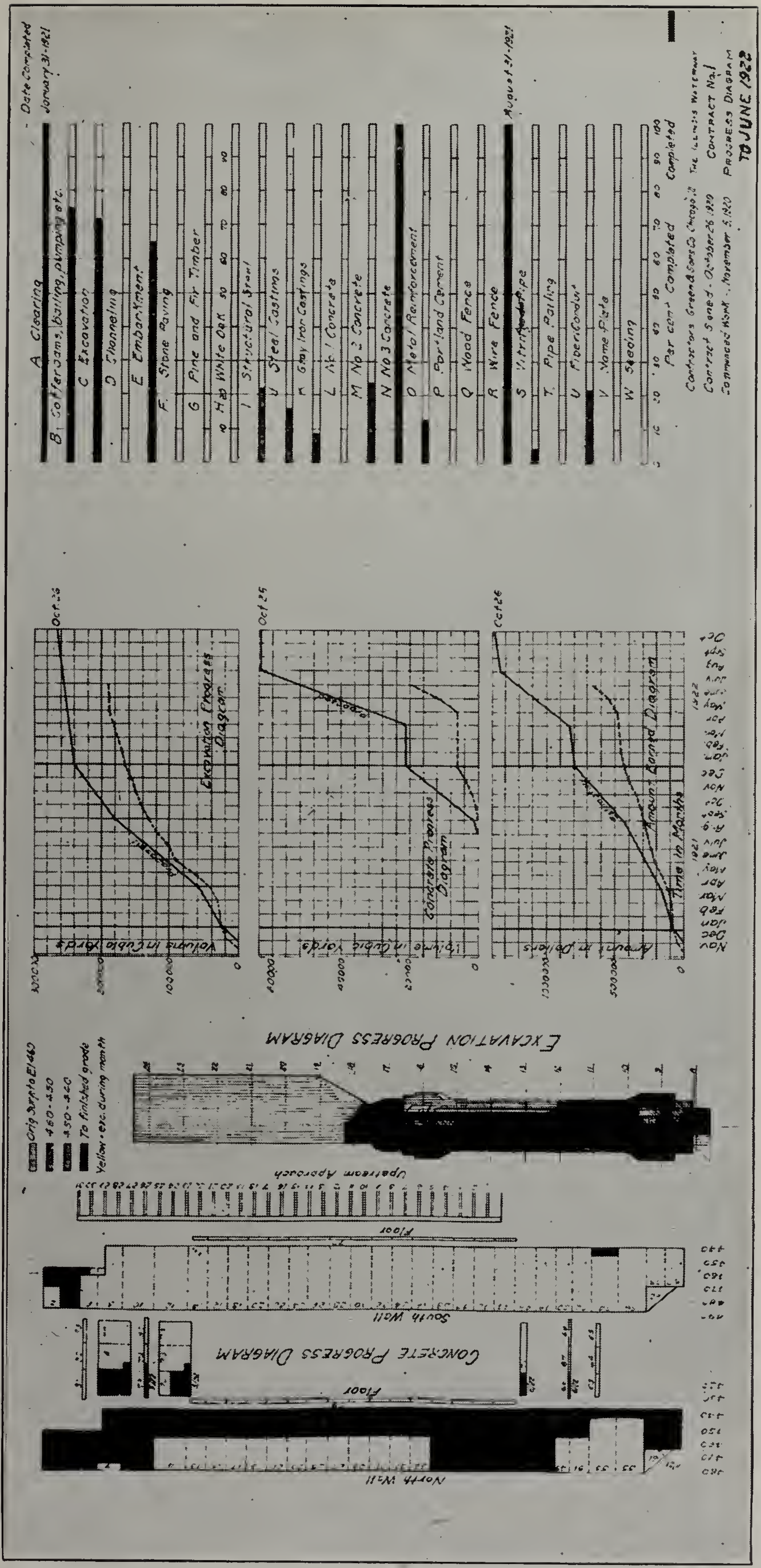


Diagram showing progress of Marseilles Lock construction.

at all times. One additional dinkie engine was provided. The small steam shovel, No. 28, was removed from the work and another one, No. 18, installed in its place.

Concrete.—Actual concrete placing began at 10:45 a. m. on September 23rd by way of a footing course for block No. 59, being the lowest downstream section of the north lock wall, and was carried on intermittently to the latter part of December, 1921. No concrete was placed during the winter months. In April a few yards were placed in the head bay paving for use as footings for the trestle bridge. In May operations were resumed in the north wall and were continuous during that month and June.

The progress of the work during the year is indicated by the accompanying chart and photo cuts. During the fiscal year the following quantities were placed or work done:

86,787	cubic yards of excavation.
19,129	cubic yards of concrete.
27,526	pounds of structural steel.
8,300	pounds of steel castings.
1,253	pounds of gray iron castings.
11,425	pounds of metal reinforcement.
88	feet of 6-inch vitrified pipe.
215	feet of 3-inch fibre conduit.

THE ILLINOIS WATERWAY.

M. G. Barnes, Chief Engineer of the Division of Waterways, January 26, 1922, discussed plans, construction and benefits of the Illinois Waterway before the Illinois Society of Engineers at Decatur. The facts given are of interest to the people of the State, and are included, together with information by other engineers, as a part of this report:

The Illinois Waterway is the official name given to the waterway to be built pursuant to referendum vote of the people of Illinois in 1908. That year the people voted to bond themselves in the amount of $20,000,000.00 for the construction of a deep waterway and water power incident thereto from Lockport to a point in the Illinois River near Utica. Since the authorization of this bond issue engineers and others have proposed various plans for carrying out the will of the people. Among these plans at least three have been given serious consideration. The first plan proposed contemplated the final construction of a ship channel from Chicago to the Gulf, of dimensions adequate to accommodate ocean going vessels. After mature consideration of this plan it is not believed feasible to construct waterways through the Illinois and Mississippi Rivers with depths sufficient to accommodate ocean vessels, and even if feasible, the cost would be all out of proportion to the prospective benefits.

The next plan proposed and for which a law was enacted in 1915 looking to its construction called for locks 55x250 feet. In the opinion of the writer this plan erred as much on the one side as the proposed ship channel did on the other. Neither plan received favorable consideration from the War Department and permit for construction was not issued. This was the condition of affairs when Governor Lowden took office in 1917. He found a mandate from the people by direct vote authorizing the construction of a deep waterway and power incident thereto; also a law enacted by the Legislature in 1915 appropriating $5,000,000.00 for its construction, and the plans for the waterway contemplated by the Act of 1915 disapproved by the War Department.

About this time, the writer was employed to review the situation, report on the various plans submitted, and recommend a plan that would fulfill the wishes of the people and meet the approval of the War Department. After reviewing all the data available, it was recommended that both plans theretofore considered should be rejected and a third one hereinafter described adopted. The following were the physical and commercial conditions found:

The rivers of the Mississippi Valley are in their natural state broad, shallow, relatively of low velocity, and excepting the Mississippi and Missouri Rivers do not carry a large amount of silt in suspension. The Illinois River traverses an alluvial valley having low banks and a much more stable regimen than is found on the Mississippi River. The slope in the stream from Utica to the mouth is very flat, averaging only .13 feet per mile. In most instances the curves are of long radius and the stream is in its natural condition well adapted to carry an enormous commerce. A hasty survey of the commerce available revealed that there was large tonnage of raw products such as coal, sand, gravel, grain and lumber immediately adjacent to the river banks awaiting a cheap means of transportation to a proper consumptive demand. This freight was supplemented by large tonnage of manufactured articles that would seek transportation between Chicago and St. Louis and points southward to the sea. Computed on the basis of the average tonnage per capita in the United States, the commerce of Chicago alone amounted to upwards of 60,000,000 tons annually. Actually its tonnage exceeds this amount. Much of this freight is north and south bound in domestic and foreign commerce. The Manufacturers of Chicago alone exceed one-third of the foreign commerce of the United States.

Experience in transportation on highways, railways and waterways has shown that the cost of transportation varies inversely to the load transported. The construction of waterways the world over has shown that they have been built too small or at least the business attracted to waterways has outgrown their accommodations. Federal engineers have realized this in planning for the improvement of the Ohio River in which stream they have designed locks 110 feet wide and 600 feet usable length.

With the conditions above enumerated prevailing there seemed to be but one answer to the problem. To be designed along economic lines, the waterway should be broad and of medium draft to meet the natural conditions of the streams to be utilized and the locks should be so designed as to accommodate fleets of large tonnage. To meet these conditions, it was recommended that the channel should have a bottom width of at least 200 feet and the locks should have horizontal dimensions of 110 feet by 600 feet and capable of passage of cargoes of from 7,000 to 9,000 tons in one lockage. The channel depth should be at least 8 feet and the locks so designed that in the future when business has increased and money is available the channel could be deepened to 14 feet.

These recommendations met the approval of the waterway interests of the State of Illinois and negotiations were at once entered into with the War Department seeking its approval of the plans for waterways based on such recommendations. In 1919 a bill was presented to the Legislature, providing for the construction of such waterway and repealing the Act of 1915. Before the bill was enacted it was presented to officers of the War Department who assured the State that the plans would be approved if presented in accordance with the bill as drawn. The bill was enacted late in the legislative session with but two or three dissenting votes and as soon as preliminary report could be presented to the War Department, the plans were approved. The alignment and profile as approved are shown on plate No. 1.

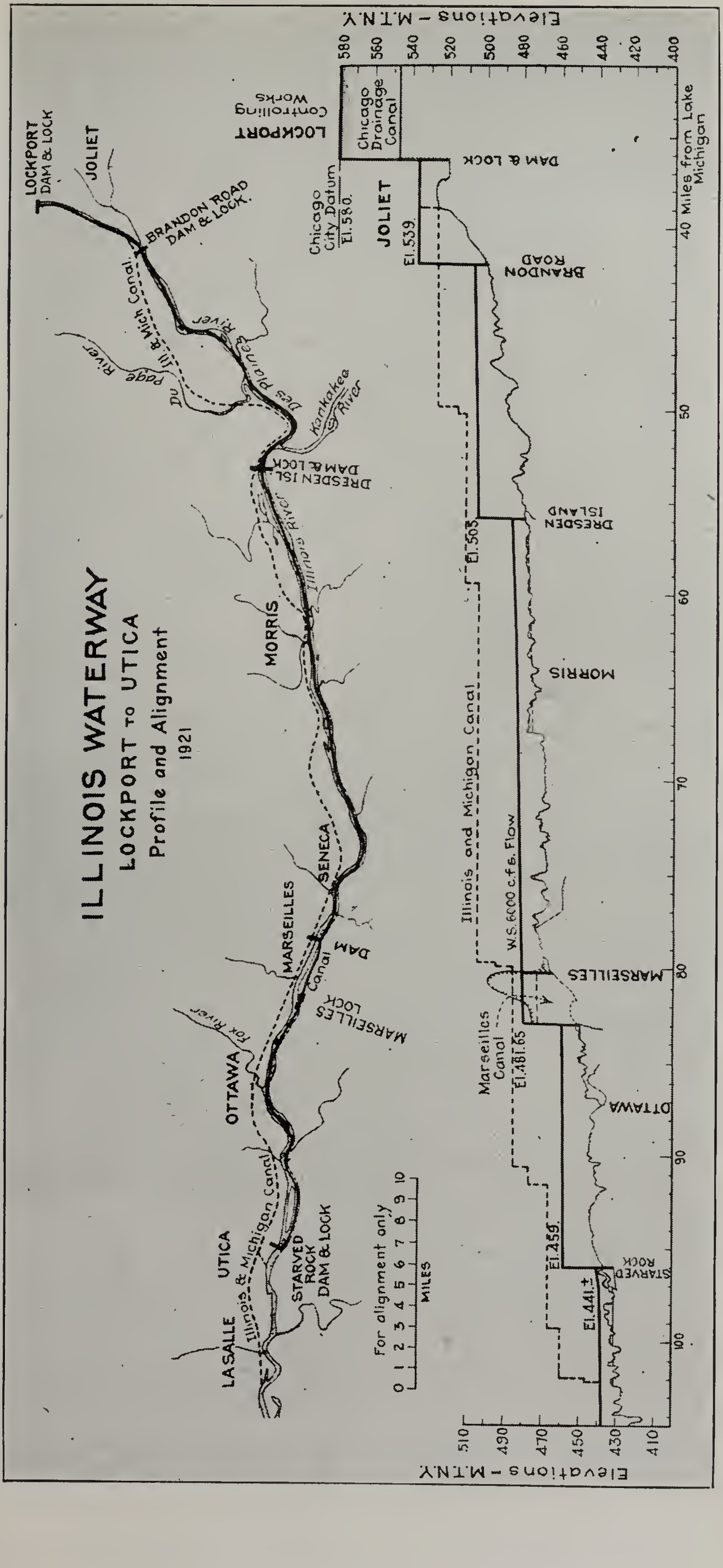
About this time, Congress was trying to pass a Federal Water Power Act, looking to intelligent development and utilization of the water power on the navigable streams of the United States. The bill finally became law and required that in the improvement of navigable streams consideration should be given to full utilization of the stream for both power and navigation purposes so as to best conserve the natural resources of the streams of the United States. In early studies for the development of navigation on the Illinois River by the Federal engineers, little attention was given to power possibilities. This was excusable from the fact that at that time water power was of little value and the transmission of power over long distances electrically was unknown. With power demand increased and the art of transmission perfected as it is today, radical changes in design for the waterway were necessary. The Sanitary District of Chicago had completed a sanitary ship canal from Chicago southwestward to Lockport, about 35 miles distant, at which point it has constructed a small lock and a power plant. This is the site for the first lock in the improvement of the DesPlaines and Illinois Rivers. At this site a lock will be constructed of the dimensions heretofore outlined and will have a lift of 41 feet connecting the Sanitary District channel with the DesPlaines River. Joliet lies a short distance below this point and its existence presents quite complicated engineering study for a waterway through the city. Several plans have been considered, among them one of utilizing the present stream with either one or two locks and another plan utilizing the old I. & M. Canal widened and having either one lock or two locks. Studies were made of all these plans and it was found that, considering the cost and utility, the best plan would be to carry the water through the city at the Lockport lower level and construct a lock at the southerly limits of the city, which would be known as the Brandon Road lock, having a lift at low water of about 32 feet. The construction of this lock will require high gravity concrete retaining walls on either bank of the river to protect the city from the new elevation of water in the DesPlaines River. The construction of this lock would also flood the mouths of all the sewers emptying into the DesPlaines River, necessitating intercepting sewers along both banks. These sewers are to be contained in the gravity retaining walls and in addition to serving their purpose as intercepting sewers will act as cut-off channels for any seepage from the river, thus preventing damage to basements.

Several sites present themselves for the next lock. The Kankakee and DesPlaines Rivers meet 12 miles below Brandon Road and form the Illinois River. The Economy Light and Power Co. many years ago purchased the riparian rights along the DesPlaines River and started the construction of a power house at its mouth, but was prevented from completing its enterprise by court proceedings. Had this work been completed, that would have been the natural site for the third lock in the series. The argument for such a location is that it avoids the flood waters of the Kankakee River. However, careful estimates have shown that the cost of building the channel approach to the lock below will be excessive, hence a new site for a lock was sought. A suitable location was found two miles below the junction of the DesPlaines and Kankakee Rivers at a point where the rock begins to disappear below what will be the improved channel of the Illinois River. This site was developed by core drill borings and after comparative estimates were made the site was adopted for the following reasons:

1. The cost for the complete waterway would be much less than by the adoption of the site above the mouth of the Kankakee River.
2. It would result in a much better navigable channel.
3. It would extend navigation five miles up the Kankakee River, which stream may later be improved for navigation purposes.
4. It best met the Federal Government's requirements as outlined in the Water Power Act.

This lock will be known as the Dresden Island Lock.

From this point down stream, the Illinois River can be utilized for several miles in its natural condition. At Marseilles private interests constructed a dam across the river pursuant to a legislative act dated 1865. This dam backs the water upstream several miles. Water power was created by this dam and several water power and manufacturing interests have grown up at that point, a consideration of which complicated waterway designs. Had these interests not been developed, the natural place for the fourth lock and dam in the series would have been about 13,000 feet further down stream where a dam should have been constructed with a crest about 5 feet above the crest of the present dam, which would have backed the water up nearly to the site of the Dresden Island lock. In order not to disturb vested interests, it was deemed advisable to either raise the crest of the present dam or construct another one a few hundred feet upstream from it with a crest about five feet above the crest of the old dam, and to



ILLINOIS WATERWAY
LOCKPORT to UTICA
Profile and Alignment
1921

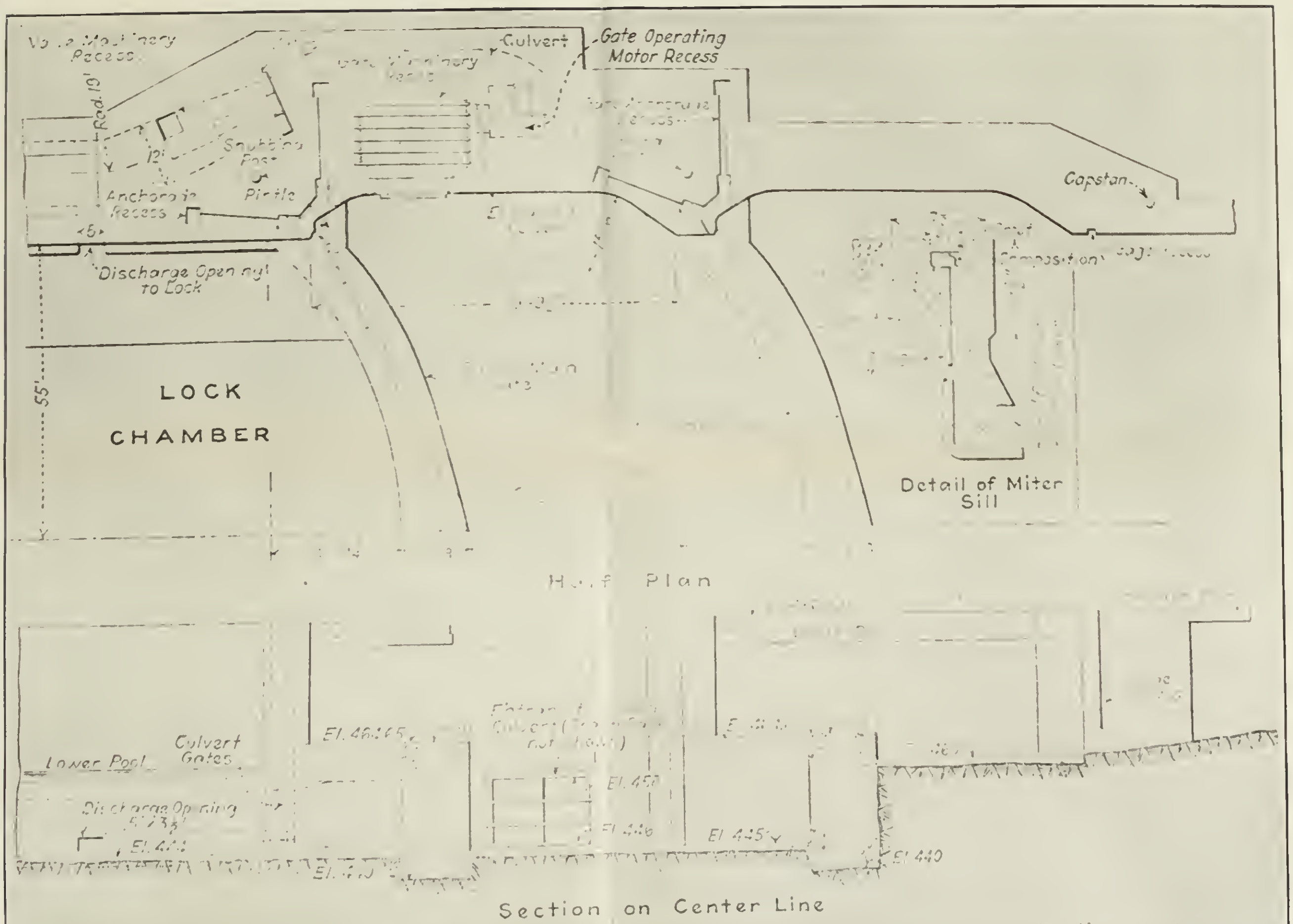
construct a diversion canal 13,000 feet long with a lock at its lower end having a lift of 21 feet and connecting with the river near the upper end of Bell's Island.

Between this point and Utica, the river contains several large tillable islands and in many places banks are low and are annually inundated, though usually much of the land is available for crops and pasture. To add to the difficulties some of the parks, school grounds, and sewer outlets at Ottawa are low and are annually inundated and would be permanently flooded by any great raise in the elevation of the water from dams downstream. Engineers have suggested various plans for the improvement of this reach of the stream. Before the enactment of the water power law, Federal engineers suggested two dams of about 8 foot lift each, one located above Ottawa and the other one at or near Utica. These dams would not flood much of the uplands and would not seriously interfere with the improvements at Ottawa. Another plan has been to construct a 16 foot lift lock and dam at Utica, which would flood all of the islands. The low lands on either bank of the stream were to be protected by long dikes or trailing walls built above flood heights. Present estimates show the cost of these walls exceeds the value of the lands to be protected; also the presence of these walls would introduce drainage problems difficult of solution. Taking all these matters into consideration, it has been thought wise to construct one lock and dam at the lower end of the reach; that is near Utica and flood all the islands and low lands.

Plans as outlined for various locks meet the requirements of the Federal Water Power Act and create large deep water pools well adapted for slack water navigation. Throughout the entire reach of the DesPlaines and Illinois Rivers to be improved the banks are low and adjacent lands are available for agricultural purposes. If dams were to be built with fixed crests, large tracts of land would be flooded during high water periods that heretofore have been above the flood plain. In order to preserve these lands dams have all been provided with movable crests so designed that they can be raised during flood periods and the high waters resulting will not materially exceed those prevailing before the improvements. Plate No. 2 shows how the structures at the Brandon Road site will look when completed.

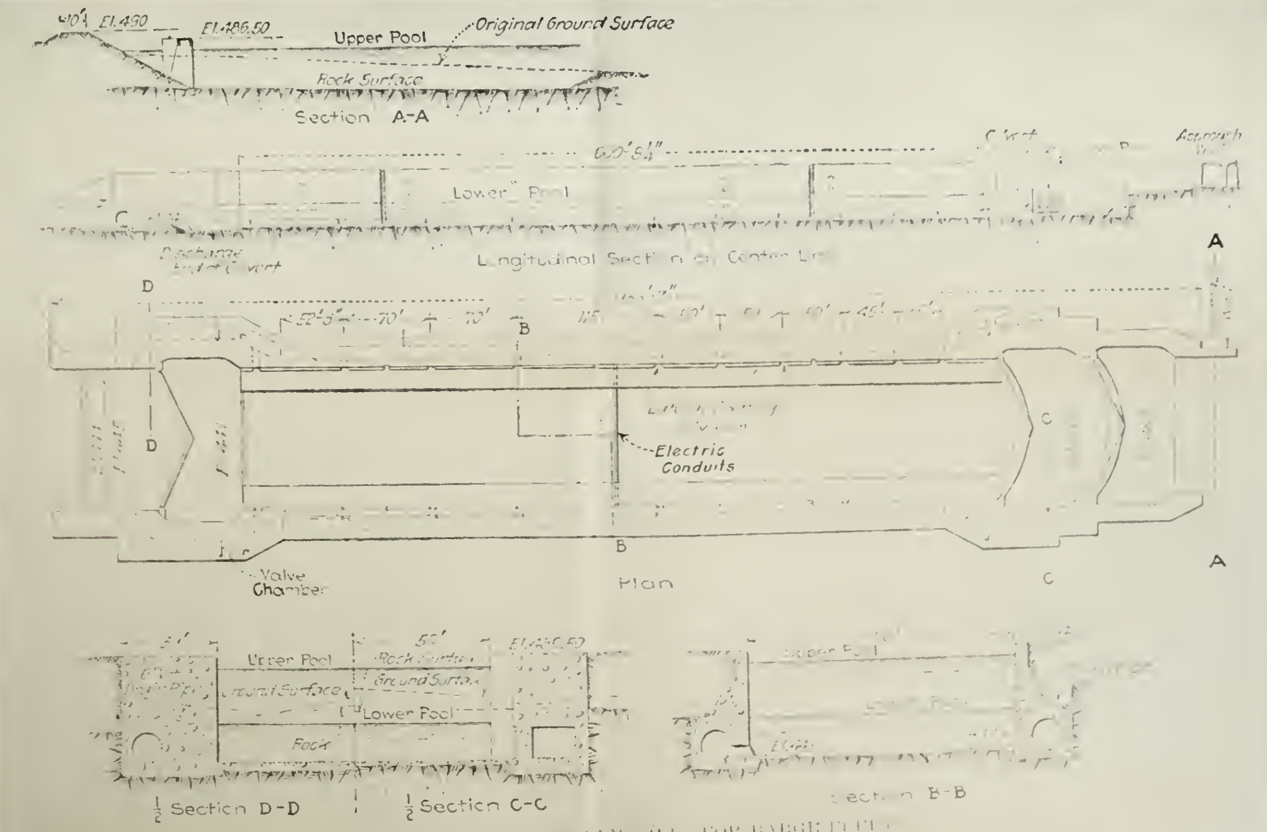
Having determined on the general features of the waterway, the detail design presented some problems not ordinarily met in works of this magnitude. To carry out these designs and construct the waterway, a force of engineers has been employed, each member of which has had educational training and experience on work of similar character which peculiarly fit him to solve the problems presented. The various members of the force have been asked to write chapters for this paper dealing with the subjects on which they have been more intimately employed. I am greatly indebted to them for their assistance in preparing these designs and in preparing the paper to be presented here today. The chapters on design and other features of this waterway were written by members of the force, whose names and position appear at the beginning of their articles. I will give a brief outline of the contents of these various chapters on design and file the original matter as part of this paper.

Hydrology.—The Illinois River is formed by the confluence of the DesPlaines and Kankakee Rivers. The former has a low water flow of less than 100 second feet and a maximum discharge of over 13,000 second feet. The Kankakee River has a mean low discharge of from 200 to 400 second feet and a maximum of possibly 40,000 second feet. At Ottawa the Fox River empties into the Illinois and below their junction the maximum discharge may exceed 80,000 second feet. The water for the summit level of this waterway is obtained from Lake Michigan through the Chicago Sanitary District Canal. The mean flow in the Sanitary District Canal now probably exceeds 8,000 second feet, and this, together with the natural flow in the streams amply supplies all the water necessary for navigation purposes and leaves a good surplus for power development. If the diversion from Lake Michigan were limited to the amount necessary for navigation purposes only, the cost of constructing the Illinois Waterway would be increased at least two million dollars.



MITER SILLS AND CULVERT CONNECTIONS AT UPPER END OF MARSEILLES LOCK

Plate No.4



LOCK AT MARSEILLES, ILL. FOR BARGE TRAFFIC

Plate No.3

Bad flood conditions prevail along the DesPlaines and Illinois Rivers during the winter season. In extreme cold weather ice forms on these streams and is met by warmer water from Lake Michigan and Chicago sewage which carries great quantities of floating ice down the stream. This ice finds lodgment on the shallow places, islands and projecting points on the shore lines, causing ice gorges that frequently do much damage to adjacent property. It is hoped that the construction of the locks and the resultant deepening of the channel will lessen the danger from these ice gorges, if in fact, they are not entirely eliminated.

Locks.—All the structures to be built along this waterway are founded on rock. Happily at the lock sites the rock is near the elevation of the foundations so that a minimum amount of excavation will be required. The greatest depth of rock excavation is found at Lockport and Marseilles, but does not exceed more than about 20 feet in either instance. The lock walls will be of the gravity type of concrete built in accordance with usual specifications for such work. Each wall contains the filling and emptying culverts, circular in form, with a diameter of 12 feet. The presence of these culverts introduce some complications in stresses. In designing these walls the method of "Least Work" was employed. A technical description of the analysis is given in Mr. Smith's paper. The miter walls are horizontal arches, also designed by the method of "Least Work." So far as the writer knows, miter walls have always been designed to receive considerable pressure from the lock gate. While the miter walls for this waterway are strong enough to receive such pressure, the gates have been designed so that no pressure of consequence can be transmitted from them to the miter walls. A metal spring has been introduced between the gate and miter sill which spring receives only the pressure from the water directly against it and forms the seal between the gate and the sill, the gate thus bearing at its miter and heel posts only. The lock gates are of the mitering type and do not differ materially from the design in use on other waterways.

The filling and emptying system is made up of two large longitudinal culverts in the lock walls with valves at either end and communicating with the lock chamber through a system of ports or small openings distributed along the foot of the lock walls. Experience has shown that in shallow draft canals less disturbance from the flow of water under head is created from this system than through the system of vertical openings through the floor adopted at the Panama Canal, Sault Ste. Marie, Michigan, and Keokuk. The flow of water through the large culvert at high velocity creates a greater discharge at the down stream ports which causes the lock to fill more rapidly at that end, the boats necessarily surging on their lines and in some instances ramming the upper gates. This phenomenon is quite marked in high lift locks. The writer has observed in some of the high lift locks on the New York State Barge Canal that in the first stages of filling the lock the water is drawn into the upper ports much as water is forced into a boiler by an injector. In order to lessen the surging in the lock chamber, these ports have been arranged at varying spaces at either end of the lock, leaving a space in the center with no ports.

Probably without exception engineers have designed the valves in the filling and emptying culverts of equal or greater cross sectional area than the culvert itself. Clemmons Herschel showed many years ago that this was unnecessary. A negligible loss of head will result if this valve is decreased in cross section with the culvert leading to and from it given flaring sides, having an angle of about 3 degrees with the sides of the culvert. The Venturi action is thus obtained and only a small loss of head results. Taking advantage of this condition cheapens the cost of the culvert and permits us to use smaller and lighter operating machinery. The valves adopted are the vertical moving truck type similar to those used on the New York State Barge Canal. except that improvements have been made in the truck wheels. These have been provided with helical roller bearings believed to possess all the advantages of the Stoney gate live rollers and to eliminate many of the objections in such a design. The lock gates are operated from a spar attached at the upper end of the gates. This spar is actuated by a bull wheel placed in the masonry after the type designed and patented by Edward Schildhauer for the Panama Canal. The machinery for all the locks will be operated electrically. Current can be obtained from local transmission lines or will be available from the power to be developed at the lock sites. Powerful towing winches will be installed at each end of the lock electrically operated and designed to tow vessels into and out of the locks.

Dams.—As indicated above the dams are all provided with movable crests so as to prevent excessive high waters and great damage to adjacent property. The Taintor gate design has been adopted for the main portions of the dams. The only new features in this design are that the hammer head type of design has been adopted instead of the usual truss or built up member at each end of the gate. The old design introduces redundant members whose stresses are unknown and consequently more material is used than is necessary for economical design. The other novel feature, if it can be called novel, is that the gates used at Starved Rock are larger than any other design yet built. These gates will have a clear opening of 60 feet and are designed to withstand a head of 19 feet. These gates can be counterweighted accurately so that the only force required to raise and lower them is that due to friction on the journals. The gates will be operated by hand or can be operated electrically if desired. Supplementing these Taintor gates the dams at Brandon Road, Dresden island and Starved Rock will be provided with a shorter span of movable crest to be used as an ice chute. The design will be similar to the Taintor gate except that instead of raising out of the water the gate will be depressed allowing the water and ice to run over its decked surface. Its movements will be manipulated by a system of valves and pipes leading to the upper and lower pools.

In all canals having important summit levels it is customary to install an emergency dam to prevent opening up the summit level in case of accident to the gates of the summit lock. The lock at Lockport has been provided with an emergency gate. This gate consists of a butterfly type of shutter normally laying in the bottom of the canal above the upper guard gate. Its under surface communicates with a drum sector in the concrete which in turn communicates with upper and lower pools through a system of pipes and valves. In case the lock gates are wrecked the pipes leading to the emergency dam are opened to the lower pool and closed to the upper pool so that the gate is drawn into its incclined position shutting off a sufficient flow through the locks so that the remaining lock gate can be closed.

Bridges.—The low banks along the Illinois River make it necessary to design all bridges of the movable type. It is not definitely determined yet whether these bridges will be of the bascule or vertical lift type. Designs are being made for both types of bridges. If the vertical type is adopted a clearance of 55 feet under the bridge in its upper position will be provided.

Thus far but one contract has been let—that for the lock at Marseilles. This contract was let October 26, 1920, and to date about 40 per cent of the work has been completed.

TRANSPORTATION COSTS.

By L. D. Cornish, *Assistant Chief Engineer.*

The average freight rate on all the railroads in the United States was about 7½ mills per ton mile for a number of years and a special group of coal roads could be selected upon which the average was about 5 mills. The increases in freight rates during the past few years has about doubled these figures. For bulk commodities such as grain, coal, sand and gravel on roads which are competitors of the Illinois Waterway and Mississippi River between Chicago, the Illinois coal fields, St. Louis and New Orleans, the present rates average about 10 mills per ton mile.

On the New York Barge Canal the rate on such commodities is about 3⅓ mills while on several European canals the rate is from 1 to 2 mills. The statistical report of lake commerce passing through the canals of Sault Ste. Marie (Soo) show that the average freight charges per ton mile steadily decreased to a minimum of 6/10 mill in 1914. Increased costs during the war and post war periods caused a rapid increase in this rate which during 1920 averaged 1⅓ mills per ton mile. The average for past 20 years has been 0.82 mills. Coal is carried at cost on account of its need for ballast and making allowance for this a fair average rate for lake traffic is 1 mill per ton mile.

To express the foregoing and other rates in a way which can be more easily visualized by the average person, they have been frequently given in the form of the number of miles which one dollar will carry a ton of freight which are as follows:

By	Miles per $1.00
Horse and wagon	4
Auto truck	20
Railroad	100
N. Y. Barge Canal	300
European canals	500
The Illinois Waterway	**750**
Great Lakes freighters	1,000
Ohio and Mississippi River downstream	3,000

Three facts relative to transportation are indisputable:

First—High freight rates are a tax on industry which restrict industrial and agricultural development.

Second—Every increase in freight rates reduces the area within which business can profitably be done.

Third—Water transportation is the cheapest of all.

The foregoing shows what has been done by water transportation, but the great question of interest, particularly to the people of Illinois, is what will the Illinois Waterway do toward providing cheaper transportation. An estimate might be made in considerable detail as to what the transportation cost should be but such estimates are inconclusive and invite attack as to their accuracy. The safest method of arriving at the probable rates on this waterway is to assume that the rate need be no greater than the actual rates on similar or inferior waterways in the United States at the present time. The reimproved navigable Monongahela River reaches 70 miles above Pittsburgh and is improved for 8 feet draft and has twin locks 56 feet by 360 feet. Its single fleet lock capacity is about 3,000 tons or 30 per cent of the capacity of the Illinois Waterway locks. In recent years the traffic on this river has been as follows:

	Tons.	Value.	
1914	10,374,000	$20,714,000	
1915	11,815,000	28,980,000	
1916	12,876,000	35,673,000	
1917	16,009,000	64,210,000	
1918	16,538,000	64,720,000	80 per cent coal and coke.
1919	14,630,000		Coal only.
1920	20,718,000		Coal only.
1921	15,000,000		Coal only — business depression.

The coal traffic is a one way haul and the barges are returned empty. Government figures for cost of hauling this coal including 6 per cent interest and 10 per cent depreciation on equipment are as follows per ton mile: 2,000-ton fleet 5½ mills, 3,000 tons 3.12 mills, 4,000 tons 2.5 mills, 5,000 tons 2 mills, 6,000 tons 1.68 mills. The decrease in cost as the size of cargo increases shown by the foregoing indicates that for 9,000 ton cargoes the cost would be about 1 mill per ton mile. These costs are for a waterway on which it is necessary to separate large fleets into 3,000 ton units at each lock. As the Illinois Waterway locks can pass 9,000 ton fleets in a single lockage, it is apparent that the above indicated cost of 1 mill per ton mile should not be exceeded on such commodities as coal, ore, sand, gravel and grain.

Surely no one can dispute the claim that the cost of water transportation between Chicago and New Orleans or long hauls to intermediate points will not exceed the profitable rates now in effect between St. Louis and New Orleans. The government-operated Mississippi-Warrior Service between St. Louis and New Orleans has steadily improved during the last three years and since April 1, 1921, has shown operating results before deductions for depreciation as follows:

April to August, profit	$324,681.10
September to November, deficit	79,324.91
December to June 30, 1922, profit	208,390.37
April, 1921, to June 30, 1922, total profit	$453,746.56

This service is operated under a joint rail and water rate which is 80 per cent of the rail rate. These rates are effective over a large territory bordering the river and for the Northern Zone shipments are by rail to St. Louis or Cairo thence by the barge line to New Orleans or intermediate points. The shipper saves 20 per cent of the through rail rate, but his saving is entirely at the expense of the barge line. The railroad gets about 31 per cent of the full through rates for its 280 mile haul to St. Louis and the barge line gets what is left. The result of this is that the barge line carries a great deal of freight from St. Louis to New Orleans at fifures which are materially less than 80 per cent of the rail rate between these points.

The barge line operating costs per ton for the fiscal year ending June 30, 1921, were as follows: Terminals $1.73, hauling $1.69, damages $0.18, and traffic and general expenses $0.52, total $4.12. Of these, haulage varies almost directly with the mileage and it is reported that for full cargoes this item is less than 1½ mills per ton mile. The average terminal costs and damage claims are very high on account of the crude way of handling freight at some of the terminals. Results obtained at their completed modern terminals give assurance that the terminal costs will be reduced to $1.00 per ton and damage claims to below the railroad average of 2½ per cent of freight receipts which for the barge line would be about 10 cents per ton. This statement is justified by the experience of the St. Louis-Kansas City Barge Line whose damage claims were 75 per cent less per $1.00 of freight charges than those of the competing Missouri Pacific Railway Company. The traffic and general expenses during the last three months have been reduced to 31 cents. These items plus $1.69 for haulage aggregate $3.10 as a liberal estimate of the operating cost per ton for barge transportation costs between St. Louis and New Orleans. The only material operating cost which should be added for through traffic between New Orleans and Chicago is the haulage cost for the additional 400 miles, which at 1½ mills per ton mile amounts to 60 cents per ton and the operating cost between New Orleans and Chicago may therefore be assumed as not exceeding $3.70.

The possibilities of profit to transportation companies and lower rates to shippers is indicated by the last column in the following tables which show the difference between $3.70 and the present Mississippi Warrior Service joint rail and water rates per ton. This difference is wide enough to justify the claim that rates on this waterway can be made as low as 50 per cent of present rail rates. Future reductions in the cost of labor and materials which may result in and justify lower rail rates will also justify lower water rates. The cost of carrying commodities varies greatly with their character, therefore the figures in the last column indicating the margin over actual cost may be badly in error for any particular item but the mean figures are essentially correct.

FREIGHT RATES PER TON C.L.L.

CHICAGO TO NEW ORLEANS.

	Rail rates.		Mississippi Warrior 1921.	Mississippi Warrior less cost of $3.70.
	1913.	1921.		
Agricultural implements	$7.20	$12.00	$ 9.90	$ 6.20
Canned goods	7.00	11.70	9.70	6.00
Dried fruit	8.20	21.80	17.90	14.20
Glucose	5.00	8.40	7.10	3.40
Packing house products	7.80	13.10	10.90	7.20
Paints—red and white lead	5.60	9.30	7.80	4.10
Rails	7.60	6.30	5.60	1.90
Salt	4.60	7.70	6.60	2.90
Soap	6.20	10.40	8.70	5.00
Starch	7.00	11.70	9.70	6.00
Steel—structural	5.60	9.30	7.80	4.10
Stoves and ranges	8.80	14.70	12.20	8.50
Varnishes	8.20	13.70	11.40	7.70
Mean	$7.44	$11.56	$9.64	$5.94
Corn for export	$4.00	$7.90	$5.38	$1.68
Wheat for export	4.00	7.90	5.68	1.98
Grain, mean	4.00	7.90	5.53	1.83

NEW ORLEANS TO CHICAGO.

	Rail rates.		Mississippi Warrior 1921.	Mississippi Warrior less cost of $3.70.
	1913.	1921.		
Canned goods	$ 6.40	$10.70	$ 8.90	$ 5.20
Coffee	5.00	12.00	9.70	6.00
Cotton	10.34	21.90	21.10	17.40
Dried fruit	7.80	21.80	17.90	14.20
Fresh fish	11.00	18.20	14.90	11.20
Glucose	5.80	9.70	8.10	4.40
Lumber	5.10	8.40	6.90*	3.20
Petroleum	4.60	7.30	6.10	2.40
Rice	7.00	11.70	9.80	6.10
Sisal (import)	5.60	10.30	7.10	3.40
Sugar	4.86	12.00	9.60	5.90
Steel Str. from Birmingham, Ala	6.00	10.00	7.00*	3.30
Mean	$6.62	$12.83	$10.59	$6.89

* Estimated rates.

The average joint rate from Chicago to New Orleans on wheat and corn for export is $5.53 per ton. Of this the railroad gets $2.65 per ton for a 280 mile haul or 9½ mills per ton mile and the barge line gets $2.88 per ton for a 1,200 mile water haul or 2.4 mills per ton mile. The all rail distance from Chicago to New Orleans is 920 miles and the all rail export rate on grain is $7.90 per ton or 8.6 mills per ton miles.

For the commodities other than grain, lumber and Birmingham steel shown in the table above, the average joint rail and water rate is $10.35 per ton of which the railroad gets $3.85 per ton or 13.8 mills per ton mile and the barge line $6.50 or 5.4 mills per ton mile. The foregoing authentic figures show that the government barge line can carry freight at a profit for about one-third the ton mile rail rates now in effect and when the Illinois Waterway is completed and modern barge lines established between Chicago and New Orleans better results can be obtained.

COMMERCIAL ASPECTS.

By M. G. Barnes, *Chief Engineer.*

With the exception of the Soo locks and channels connecting Lake Superior and Lake Huron and the canalization of the Monongahela River for 70 miles above Pittsburgh, no other waterway in the United States ever had as bright prospects for developing capacity tonnage as has the Illinois Waterway.

The tonnage per year through the Soo locks for a period of 25 years from 1891 to 1916 increased from 9,000,000 to 91,888,219 tons, an average increase of 3,320,000 tons per year. Traffic fell off during the war period but the average for the past five years has been 81,000,000 tons of which 55,000,000 tons was eastbound iron ore for eastern steel districts and Chicago, 220,000,000 bushels of grain for Eastern States and the seaboard and 16,000,000 tons of eastern coal to supply the Northwest States. The traffic on the Monongahela River has now reached the capacity of the locks and amounted to 24,000,000 tons in 1920 of which 21,000,000 was coal.

The Illinois Waterway will have a capacity of 60,000,000 tons per annum and its prospects of attaining capacity tonnage are just as bright as either the Soo or Monongahela River. This waterway is comparable with the waist of an hour glass connecting the Great Lakes-St. Lawrence, New York Barge Canal systems, the North Atlantic Ports and Europe with the Mississippi River system of 15,000 miles of inland waterway, the Gulf ports, South America, the Orient and our West Coast States.

If commerce were dependent entirely upon water transportation, the commercial strategic value of this waterway would be excelled only by the Suez and Panama Canals and Chicago would be the metropolis of the world.

The valley of the Mississippi River and its tributaries is the most productive region in the world for food, forest, mine and manufactured products.

Statistics of the Department of Commerce show that 18 tons of products originate each year for each person in the United States. As the Mississippi Valley is the greatest producing area 20 tons is a low figure for this section. The population of this section is 60,000,000 and on this basis its product is 1,200 million tons.

Chicago is the greatest distributing center in the United States and there can be no question as to the possibilities for capacity tonnage for this waterway if water rates are low enough. Illinois alone originates enough mine and farm products to assure its commercial success.

Chicago now consumes 30,000,000 tons of coal per annum and the consumption is increasing at the rate of 1,000,000 tons annually. About one-half of this coal comes from Southern Illinois mines within 50 miles of navigable water. Coal from these mines can be delivered in Chicago by water for $1.00 per ton less than present freight rates, consequently a large coal tonnage through the waterway can be depended upon. The writer has been approached by and has held many conferences with officials of various corporations seeking information relative to terminal facilities, fleet capacity of the waterway, date of completion, etc. The aggregate tonnage through the waterway for which these corporations are planning totals 15,000,000 tons of coal and 5,000,000 tons of ore.

The steel mills of the Chicago and Gary districts receive annually by lake about 8,000,000 tons of iron ore and the freighters which bring it return empty. With Illinois coal costing $1.00 less per ton, these freighters could make a rate for delivery at upper lake ports and compete successfully with freighters carrying eastern coal.

Illinois produced in 1920 about 214,000,000 bushels of grain from the area within 40 miles of this waterway and the Illinois River. In 1921 the Port of Chicago shipped 78,000,000 bushels of corn by Great Lakes carriers. This quantity equals 63 per cent of the 1920 corn production of the State within 40 miles of the waterway. It will be possible to haul the export portion of the grain produced in this area by trucks to the waterway and in barges to either Chicago or New Orleans at rates materially lower than rail rates.

On the banks of this waterway are found the immense deposits of the commercially famous Ottawa sand, large quantities of which are used by every steel company and foundry from St. Louis to Gary and to points along the Ohio River and the Great Lakes. Also along the banks of this waterway are found inexhaustible deposits of sand and gravel mixed by nature in the proper proportions for concrete so that after separation by screening there remains a very small percentage of waste material. Chicago's annual consumption of sand and gravel is over 3,000,000 cubic yards.

The foreign and domestic commerce of the principal Gulf ports in 1913 amounted to 16,764,505 tons. These ports are all either now connected, or very soon will be connected, by an inland water route with the Mississippi River. The present tonnage between St. Louis and Chicago is approximately 2,500,000 tons annually, equally divided between north and southbound freight. On Mississippi River from St. Louis to its mouth is found the great cotton, rice and cane sugar belt of the United States where 56 per cent of the cotton, 92 per cent of the rice, and practically all of the cane sugar produced in the United States are raised. In addition to these crops vast quantities of the products of mines and forests are also produced. Sugar refineries of Louisiana have increased their $12,000,000 output in 1890 to about $64,000,000 in 1909, and are the largest sugar refineries in the world. At the upper end of the valley the Twin Cities and Chicago are the receiving and distributing points of the grain belt, raising annually approximately 5,000,000,000 bushels of grain and vast herds of live stock. The commerce of Chicago, as reported by the Chicago Board of Trade, amounted to upwards of 22,000,000 tons in 1897, and over 40,000,000 tons in 1907, nearly doubling in that decade. The total manufacturers of Chicago in 1917 were $2,464,241,250.00. The value of the wholesale trade exceeded $3,000,000,000, the latter figure being approximately one-third of the total foreign commerce of the United States for that year. The Department of Commerce and Labor computes that the value of the export trade is approximately $36.00 per ton, and the import trade $63.00 per ton. The mean of this is approximately $50.00. At that rate Chicago's manufactures in 1917 amounted to approximately 50,000,000 tons and its wholesale trade 60,000,000 tons. Undoubtedly some of these items are counted twice, but it is fair to assume that the total commerce of the city in 1917 exceeded 80,000,000 tons. This is at approximately the same rate of growth as the proceeding decade.

Chicago's coal receipts and shipments for 1897 were 7,763,680 tons, and in 1907 were 17,508,492 tons. The figures for 1917 are not available. Coal used in 1918 in Chicago district (estimated) 26,000,000 tons, about half of this coal being produced in Illinois. Lumber receipts and shipments for 1907 were 3,457,204,000 feet, and for 1917 were 4,873,000,000 feet, of which receipts, 1,500,000,000 feet were from Southern States and which could be shipped by water.

Of course not all of this commerce is north and south bound. However, the trade seeking that route is increasing rapidly. The opening of the Panama Canal has given still greater advantage to the Central West in securing an outlet for South American and Oriental trade. In the fiscal year ending June 1915 the port of New York handled 72 per cent of the foreign commerce of the Atlantic coast. It has been recognized for a long time that the port is congested and cannot economically handle its trade. The present condition emphasizes the necessity of seeking another outlet for this trade. The best of all water routes is down the Mississippi Valley from Chicago and St. Paul to New Orleans and other Gulf ports. The importance of that route has already attracted attention and modern terminals are being constructed.

In the trade with Central and South American countries in the decade just preceding the present war, New Orleans with Honduras had increased 88 per cent; with Mexico, 200 per cent; with Cuba, 60 per cent; with Argentina, 50 per cent; with Brazil, 58 per cent; with Chile, 389 per cent, and with Peru, 594 per cent. The value of agricultural machinery exported to South America in 1911 exceeded $9,000,000, an increase of 100 per cent in five years. Chicago houses shipped from 1,500 to 2,000 cars of farm implements a year to South America, and would ship more if facilities existed for forwarding promptly.

A few examples will be cited to show the amount of commerce in single commodities that may be expected and the vessels required to conduct them when an adequate canal is once completed. Let it be assumed that Chicago is the consuming and distributing point of only five million people. At the average per capita consumption in the United States this requires 210,000 tons of sugar, 30,000 tons of coffee, 40,000 tons of rice, and 20,000 tons of canned goods. Sisal imported into Chicago through New Orleans exceeds 125,000 tons annually. These are commodities raised in the Southern States or imported into them. To transport this tonnage to Chicago it would require seven fleets of five barges each, each barge hauling 750 tons, to transport the sugar; one fleet of five barges to bring the coffee; 2 fleets to bring the rice and canned goods to this port, and 4 fleets to bring the sisal. When normal freight rates are again established on the ocean an immense amount of Pacific coast lumber will reach the Gulf coast for distribution inland. About 60 per cent of the total amount of lumber used in Chicago now comes from the Gulf States. This amounts to about 3,000,000 tons and undoubtedly enough will seek water transportation to keep several fleets of boats constantly employed.

COAL.

It has been estimated that upon the completion of the Illinois Waterway 15,000,000 tons of coal will seek transport over the Illinois and Mississippi Rivers to Chicago and points north. Should this take place much railroad property required in normal times will be released for the transportation of other commodities. An estimate of the cost of such property is obtained in the following manner. Most of the Illinois coal that reaches Chicago comes from the southern counties and from the Springfield District, distances ranging from 180 to 300 miles by rail or an average of say 240 miles. The average rate of speed for cars on railroads in the United States is about 30 miles per day and the capacity of coal cars is about 50 tons. It is estimated that loaded trains will be made up of 40 cars and empties of 80. Under these assumptions the following figures are derived. One car would make 23 round trips per year (assuming constant use) and haul 1,150 tons per annum. It would, therefore, require 13,040 cars and 200 locomotives to transport 15,000,000 tons of coal to Chicago. The value of this property is:

13,040 cars at $3,000 each	$39,120,000.00
200 locomotives at $50,000 each	10,000,000.00
Total value of rolling stock	$49,120,000.00

The Interstate Commerce Commission estimates that cars and locomotives on the railroads of the United States amount to 21 per cent of the total value of all railroad property. If this is true, the total value of all railroad property released in the transportation of coal alone, by the construction of the Illinois Waterway, is $234,000,000. It will require about $30,000,000 to $35,000,000 worth of property to transport this amount of coal by water including the terminal facilities or a net saving of $200,000,000 worth of transportation property, which at 6 per cent interest amounts to $12,000,000 annually.

The rail rate on coal from Southern Illinois to Chicago is $2.17 per ton. It has been estimated that with the completion of the Illinois Waterway fleets of barges with a capacity of 9,000 tons can transport this coal up the Mississippi and Illinois River to Chicago at a saving of $1 per ton. This does not seem unreasonable in the light of experience and on other waterways transporting similar commodities. Coal is hauled on the Great Lakes, a distance of 1,000 miles at 30 cents per ton. In 1920, 21,000,000 tons of coal were transported over the Monongahela River to Pittsburg in smaller barges and through smaller locks than will obtain on the Illinois River, a distance of 65 miles, for less than 10 cents per ton, while the railroad charge for the same distance was 85 cents per ton.

In the construction of the Illinois Waterway there will be developed as a by-product about 55,000 horse power years of electric power. This will result in an annual saving of 550,000 tons of coal as ordinarily developed in steam plants. The saving of this amount of coal would release $1,800,000 worth of rolling stock or $8,500,000 worth of rail property. At 6 per cent interest this shows an annual saving of $510,000. Statistics of the United States census show that the consumption of power from central power stations in the United States is about 160 horse power per thousand of population. At this rate the power developed is sufficient for a population of 344,000 people, 5 per cent of the total population of the State, and equal to the total population of river counties, Will, Grundy, LaSalle, Marshall, Peoria and Woodford.

The 1921 price of the coal f.o.b. mines in Illinois and Indiana and rail rates to Chicago are shown in the following table:

SOUTHERN ILLINOIS.

Freight rate to Chicago, $2.17;

Prepared sizes	$3.50@4.05
Mine run	2.75@3.00
Screenings	1.85@2.25

NORTHERN ILLINOIS.

Freight rate to Chicago, $1.54;

Prepared sizes	$4.25@4.50
Screenings	2.50@3.85

SPRINGFIELD DISTRICT (CENTRAL ILLINOIS).

Freight rate to Chicago, $1.83½;

Prepared sizes	$2.75@3.50
Mine run	2.25@2.75
Screenings	1.75@1.85

INDIANA, FOURTH VEIN COAL.

Freight rate to Chicago from Sullivan County, $1.92;
from Clinton, $1.78;

Prepared sizes	$3.00@3.75
Mine run	2.60@2.90
Screenings	2.00@2.25

INDIANA, FIFTH VEIN COAL.

Freight rate to Chicago from Sullivan County, $1.92;
from Clinton, $1.78;

Prepared sizes	$2.60@3.00
Mine run	2.25@2.60
Screenings	1.50@1.75

This table shows an average of about $2.65 per ton for mine run of coal f.o.b. cars at the mine at an average freight rate of $1.87 per ton, or a total of $4.52 per ton f.o.b cars at Chicago. At these prices, the value of coal saved annually by the development of power along the Illinois Waterway amounts to $2,486,000. If the price of coal and freight are finally reduced to $3 per ton, the saving would amount to $1,650,000 annually.

The total benefit from the transportation of coal by water and the saving in coal due to the development of power along the Illinois Waterway is as follows:

Interest on transportation property released	$12,510,000.00
Coal saved by development of power along the waterway	1,650,000.00
Saving in transportation on 15,000,000 tons of coal at $1 per ton	15,000,000.00
Total annual saving	$29,160,000.00

Before the war the cost of producing power in the United States by steam was $70 per horse power per year. If power developed incident to the construction of the Illinois Waterway is sold at $30 per horse power per year, the annual saving will amount to $40 per horse power or $2,200,000 annually. This is 5 per cent on $44,000,000. Computed on the saving of coal only, i.e. $1,650,000 annually this power represents at 5 per cent interest a capital of $33,000,000.

The development of one horse power saves the labor of 35 men per year. The development of 55,000 horse power will save the labor of 1,925,000 men annually.

The benefits to be derived from cheap hydro-electric power obtained from Niagara Falls has been heralded far and wide. Its fame is noted the world over. The wheels of commerce and transportation through a radius of 200 miles from Buffalo receive their energy from the falls of the Niagara River. Yet as great as this power is it does not equal the power developed by steam in the Chicago District. Every pound of this coal is transported to the power houses for a distance of over half the length of the State. This coal comes from near the banks of navigable waters of Southern Illinois. Practically all of it should and could be brought to Chicago by water and could be delivered to the very doors of the great power plants at an annual saving to taxpayers of Northern Illinois sufficient to pay 4 per cent dividends on the entire cost of the waterway.

As startling as these figures are, they only tell of the benefits of the handling of one commodity—coal.

THE ILLINOIS WATERWAY.

(Special Articles by The Staff of the Chief Engineer.)

FILLING AND EMPTYING SYSTEM.

By L. D. Cornish, *Assistant Chief Engineer.*

The principal requirements of a lock filling and emptying system, due regard being given to economy, are that it shall permit equalization of levels in a reasonable time, will not create dangerous water disturbance in the locks or approaches and will not allow excessive waste through leakage.

A large circular culvert in each lock wall was adopted without study as the economy of such design has been demonstrated by past experience. Studies showed that two culverts 12 feet in diameter would ensure equalization of levels in from 7 to 12 minutes depending upon the location of the lock and subject to the limitation in equalization of four feet vertically per minute.

The systems at the Soo and the Panama Canal lock are conspicuous examples of attempts to secure a uniform distribution of flow into the lock chamber and also of out flow from Panama locks. The Soo locks have large longitudinal filling culverts under the floor with small uniformly spaced vertical outlets into the chambers. Both the filling and emptying systems of Panama locks consist of large longitudinal culverts in the lock walls with transverse or lateral culverts leading therefrom under the floor. There are 21 laterals with a total of 110 uniformly spaced vertical inlets or outlets. Investigation and inquiry develops that these systems possess no material advantage commensurate with their additional cost over a system of longitudinal culverts in the lock walls with horizontal openings directly into the lock chamber immediately above the floor as adopted for this work. In fact the Soo and Panama systems are objectionable for shallow draft canals and flat bottom boats and barges as used on the Mississippi River and its tributaries. Vertical jets create a greater disturbance in shallow water and cause violent movements of boats and fleets of barges which cannot be foreseen and provided for. That these disturbances occur is constantly shown in the operation of the Keokuk lock on the Mississippi, the filling system of which is similar to the Panama system.

The correct design of a lock filling system has until recent years been a disputed question among canal engineers owing to the lack of experimental data. In the Panama locks the openings into the lock chamber were as evenly spaced as the plans permitted, but tests under operating conditions show conclusively that the flow into or out of the lock chambers is far from uniform. The maximum flow in both cases is from the openings nearest to the lower end of the chamber and the minimum flow is from the upstream openings and ranges from 49 per cent of the maximum to a negative or reverse flow under certain heads. Such a condition of flow induces a current and drift of boats towards the upper gates when filling and lower gates when emptying, which is very objectionable owing to the danger of boats ramming the gates.

The Panama tests developed data which permit of a close approximation of the number and size of openings required and their relative discharge capacity. Using these data it was found for the Illinois Waterway locks having a main culvert area of 113 square feet that ten openings, each having an area of 17.5 square feet, would develop the capacity of the main culvert and that the six upstream openings or ports had approximately the same capacity as the four downstream ports. Therefore, six ports were located above and four below the transverse axis of the lock. The distance between the two culverts nearest this axis is 115 feet. With this arrangement the drift from each group will be approximately equal in intensity and when filling will be toward the center of the lock thus automatically centering the vessel in the lock chamber so that it will not drift toward the miter gates. When emptying a chamber the drift will be away from the center but with large boats or fleets of barges the drift effort from the two groups will tend to neutralize each other. Furthermore, a good distribution in emptying is not so essential because the violent water disturbances are due to the dissipation of the energy of the flowing water and when emptying a lock this dissipation of energy takes place in the culverts and tailbay and not in the lock chamber as is the case when filling.

The culverts are controlled by lift gates located at each end of the locks. The culverts draw from the upper pool through intakes enlarged to 201 square feet at the entrance. Screens are provided at the intakes to prevent drift from entering the culverts.

CULVERT VALVE CHAMBERS.

By WALTER M. SMITH, *Chief Designing Engineer.*

For some unknown reason it has been the practice of canal engineers to design culvert valves having a considerably larger opening than the area of the culvert, whereas it has been the practice of water supply engineers to put gates in a conduit or pipe line of a considerably less area than the area of the conduit or pipe, knowing that if the reduction in area is not very great the loss of head is negligible and the smaller gates are much more economical.

Herschel took advantage of this fact in the invention of the Venturi meter. In 1887 he performed many experiments on venturi tubes of two different sizes and showed conclusively that if a tube be contracted to a diameter of one-third its former diameter, then expanded to the former diameter at an angle on each side of not over 2½ degrees that the loss of head in contracting, passing through the throat and expanding was only .00173 Vt^2, Vt being the added velocity at the throat. This was true for all values of Vt from 2 to 35 feet per second. In the following computations let:

A = Area of lock chamber in plan = 110x681 = 74,910 sq. ft.
h = Head or lift in feet.
a = Combined area of two culverts in sq. ft. = 113x2 = 226.
C = Constant; varying from 0.75 to 1.15.
g = Acceleration of gravity = 32.2 ft. per sec.
t = Time required to fill lock chamber in seconds.

The formula for finding the time required for filling a lock chamber is

$$t=\frac{2\times A\times\sqrt{h}}{C\times a\sqrt{2g}}$$

and it has been the practice to take C = .75. It was found in testing the Panama Canal locks after completion where the valve area is much greater than the culvert area that C = 0.83. Using this value in the formula the time required to fill the Marseilles lock if the rise be unlimited and $h = 21.6$ ft. is $t = \frac{2\times 74910\sqrt{21.6}}{0.83\times 226\sqrt{64.4}} = 464$ seconds = 7 minutes and 44 seconds. The volume of the prism of lift is about 1,620,000 cu. ft. If there were no contraction at the valves the average velocity would be $\frac{1,620,000}{464\times 226} = 15.5$ ft. per second. The velocity through the valves which have been adopted; i. e., $9'\times 9' = \frac{1,620,000}{464\times 162} = 21.5$ ft. per second or a difference of 6.0 ft. per second. The loss of head is $.00173\times 6.0^2 =$ about .062 ft.

In testing the valves in the main gate house at Ashokan Reservoir of the Catskill Water Supply System for New York City which were built as these culverts are designed, and discharge under the same conditions, an average coefficient of .15 was obtained until a sufficient head was obtained to break the venturi action when the coefficient dropped suddenly from a maximum of 1.18 to 1.10 and steadily decreased as the head increased. This draft tube action was not lost until a velocity of about 48 feet per second was obtained, the flare of the sides being the same as Herschel's venturi meters, 2½ degrees. As there will not be such high velocities in the culverts in these locks this flare has been made an average of 3 1/3°.

Assuming that a coefficient of 1.15 will be obtained in the valves constructed in this manner and substituting this coefficient and the area of the valves for the area of the culverts in the formula the time required will be $t = \frac{2\times 74910\sqrt{21.6}}{1.15\times 162\sqrt{64.4}} = \frac{74910\times 4.652}{1.15\times 81\times 8.02} = 467$ seconds, making an increase of 3 seconds in the time of filling the lock due to using the smaller size of valves. This shows that with this size and type of valve the time of filling and the time required for passing through the locks will not be materially increased by using the smaller valves unless the coefficient falls below 1.15 which is not at all likely. In Herschel's experiments where the proportions of the diameter of the conduit to the diameter of the throat of the meter was 3 a coefficient of 2.4 in the meter with 4 inch throat in 45 runs, and a coefficient of 3.0 in the meter with 3 foot throat diameter in 49 runs was obtained. In the smaller meter the velocity in many of the runs was over 50 feet per second and was over 40 feet in 15 of them. In the larger meter the highest velocity was about 35 feet and only 14 were over 30 feet per second.

If a coefficient of 1.10 only should be obtained in the valves the increase required in filling one lock is only 25 seconds and the time of the boat in going through the five locks by less than three minutes.

CULVERT VALVES.

By L. D. Cornish, *Assistant Chief Engineer.*

The valves for controlling the filling and emptying system of the locks will be of the vertical lift gate type. The maximum head to which these valves will be subected varies a great deal according to the location of the locks but as there would be little or no economy in modifying the structural members, one design has been adopted for all locks.

Counterweighted valves of the Stoney type were considered but rejected in the interest of simplicity because of the complications in masonry and machinery design caused by the counterweight and roller trains of Stoney gates.

The valves as adopted are of the wagon body type and the only thing new in their design is the use of roller bearing wheels, as shown on Plate No. 6. Ordinary journal bearing wheels produce high friction loads and lubrication under water is so impracticable that it is seldom attempted. Stoney trains of live rollers are theoretically ideal from the friction point of view but are mechanically troublesome to operate.

Roller bearing wheels possess practically all the advantages and none of the objectionable features of journal bearing wheels or live rollers and the development in the science of their manufacture permits their use for these valves as the maximum load per wheel is about 27,000 pounds, which is within the safe limit of load guaranteed by the manufacturers of Hyatt roller bearings. The section of wheel shown in the plate indicates the use of Hyatt roller bearings, this type being preferred on account of the flexibility of the Hyatt helical roller. These bearings will be lubricated and preserved from the oxidizing effect of water as the rollers will run in grease and the design is such that the grease cannot escape except with considerable difficulty and can be easily renewed.

Each valve is approximately 10 feet by 11 feet 6 inches and will close an opening nine feet square. The valves are built up of three horizontal 18 inch, 55 pound I beams. The downstream bottom flange of the lower beam is cut off and holes provided through the web—the object being to facilitate the flow of water and operation of the gate under high heads. With this design of the bottom girder a vacuum will not be formed by the fast flowing water when the gate is open only a few inches. The skin is placed on the upstream face of the gate and consists of buckle plates which will be under tension. The valves will be raised by chains connected to the operating machinery. A vibratory or chattering motion of the valves is limited to one-fourth inch laterally by the clearance of side rollers attached to the gate and to the same amount upstream by the clearance between metal parts of gate and valve chamber.

The bottom water seal will consist of a 1¼x1½ inch strip of rubber attached to the gate which will bear on a T bar when the gate is closed. The side seals will be made by the contact of beveled edges of steel plates on the gate and attached to the masonry of the valve chamber. The top seal will be made by the contact of rubberized fabric hose attached to the gate and one leg of an inverted T bar attached to the masonry.

Based on actual tests of similar valves of the Panama Canal locks it is expected that the leakage of these valves under a 41 foot head will not exceed one-half cubic foot per second.

MITERING LOCKED GATES.

By L. D. Cornish, *Assistant Chief Engineer.*

With the exception of the upper gates for the lock at Lockport all lock gates will be of the mitering type.

There will be in all 13 miter gates of two leaves each, the total weight of which will be about 3,000 tons. The leaves are 65 feet long, 7 feet wide, and vary in height from 20 to 59 feet, and in weight from 60 to 350 tons.

Structurally each leaf consists of several horizontal girders rigidly connected to a miter post on the free end and a heel post on the hinge end. The leaf is stiffened vertically by five sets of diaphragms between all girders. The miter and quoin posts are built of structural steel shapes as shown on plate 6, the web plate being in sections which extend well in between the girder flanges as vertical diaphragms which transfer the thrust of the leaves along the quoin and miter posts to the web plates in the horizontals. The sheathing or skin plates are on the downstream side. Buckle plates were used where possible and they will be in tension except where a double skin was used to form air chambers. Intercostals are not necessary with buckle plates; hence this type of sheathing costs less than flat plates.

No other type of gate was considered as mitering gates have long been the standard form for canals and have given excellent satisfaction in operation and maintenance. It has been shown from estimates based on actual designs that usually for the lock as a whole the most economical rise of mitered gates is approximately one-fourth the lock width and that for a leaf 65 feet long the economical width of the horizontal girder is about seven feet and that the flanges should be straight except for a short curved length near each end of the upstream flange.

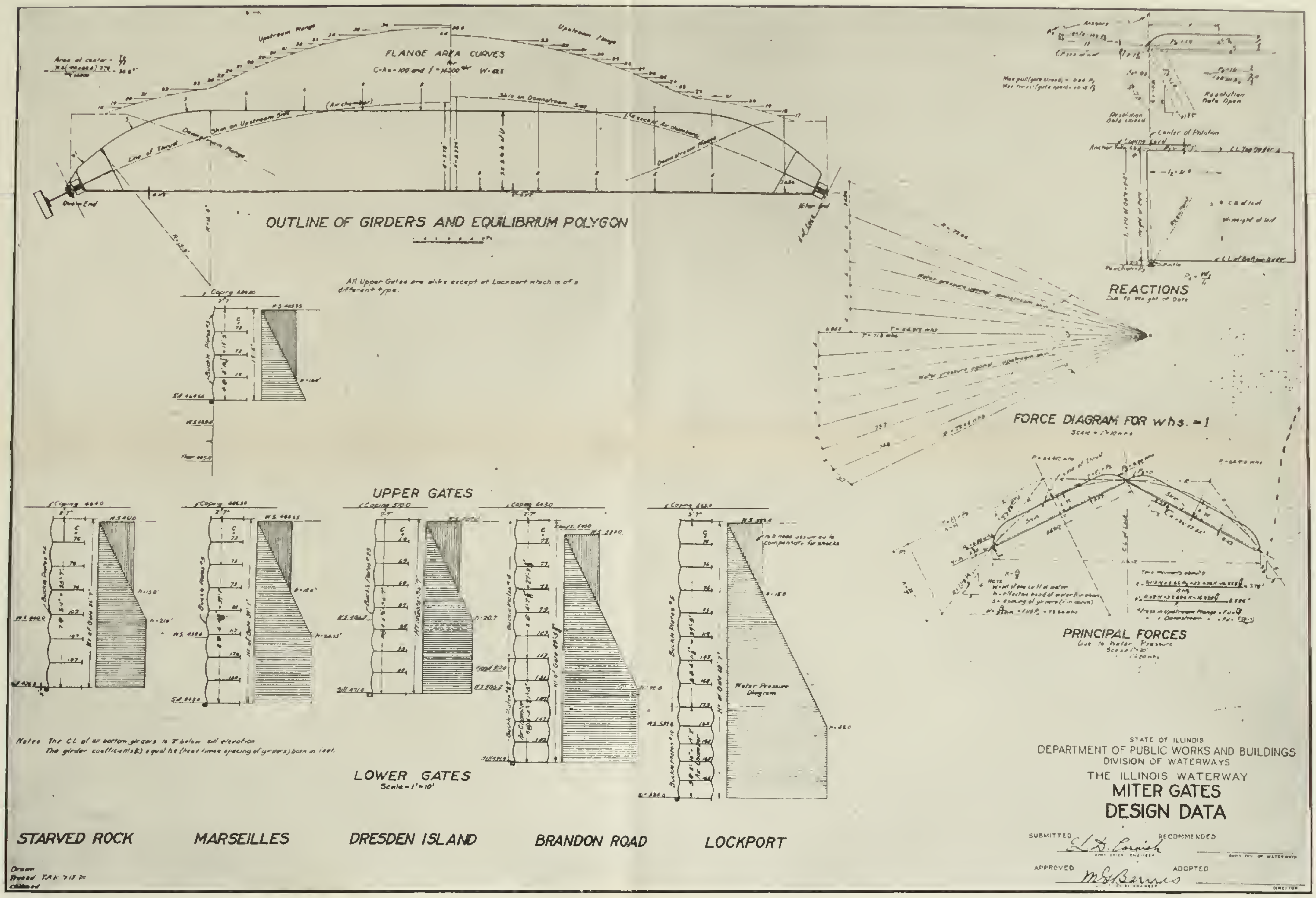
Air chambers were required for the bottom 15 feet of the Lockport and Brandon Road lower gates in order to utilize their buoyant effect to reduce the working reactions on the pintles and hinge pins. These air chambers are formed by the addition of sheathing plates on the upstream side for which buckle plates in compression were used except along the curved portion where flat plates supported by intercostals were necessary. The bearing plates along the quoin and miter posts are of steel with convex curved surfaces. The bearing plates in the hollow quoin or reaction post are also steel but with a concave surface the radius of which is slightly greater than the convexity radius of quoin post. The bearing plates are accurately aligned with set screws after which melted babbitt metal is poured into the spaces left for that purpose behind the plates.

The determination of the stresses in the gate and gate anchorage is not discussed at length in this paper as it would involve only a repetition of what has been written before.

On Plate 5 is shown graphical analysis of the principal forces acting on a gate and the equilibrium polygon and flange area curve for a girder the strength coefficient (C) of which equals 100. On the diagramatic cross sections of the various gates for the waterway are shown the girder spacing and the coefficient (C) of each girder. The water pressure diagrams show the actual or assumed head acting on each leaf and in all cases the coefficient (C) equals (hs) the product of the head (h) and the girder spacing (s) both in feet. The load per linear foot on any girder equals (WC) where (W) equals 62.5 pounds, the weight of a cubic foot of water. As the required cross sections of girders are directly proportional to their coefficients a correct determination of flange areas required for a gider whose coefficient is say 100 solves the flange area requirements of all girders. It should be noted that the total flange stresses are less when the skin is on the downstream side than when the skin is on the upstream side. The difference is due to the force P_2 shown for the left hand leaf in the analysis of "Principal Forces."

Contact at Miter Sill.—It has heretofore been the practice in the design of mitering gates to permit close contact and heavy bearing between the lower gate girders and miter sill. The result of such design does not permit of an accurate and scientific design of either the lock gate or miter wall. Both must be designed unnecessarily strong to withstand unknown and indeterminate but assumed heavy pressures. This has been remedied by placing a metal sealing spring on the gate which alone will be in contact with the miter sill when the gate is closed, and which cannot transmit to the sill more than a part of the pressure due to the water in contact with the spring itself. This permits a more accurate and lighter design of both gate and miter wall and results in decidedly lower costs.

The *gate anchorage* designs for these locks differ in many respects from any other designs of which the writer has knowledge. Large gate anchorages usually are extended deep into the large mass of concrete against which the gate abuts and are made up of eye bars on a riveted structure. Such anchorages are difficult to set and hold accurately while the concrete is poured. To secure the same results, i. e., to carry the pull of the gate when hanging free well down into the concrete mass, the gate reaction monoliths of these locks are reinforced by a network of reinforcing bars and only straight eyebar anchors are used, the anchor end of which is about four feet below the coping level of the concrete. Troughs are left in the concrete so that the bars may be accurately set at leisure and subsequently concreted in. Plate 6 shows the anchor layout. A rather fine adjustment of the rotation axis of a gate is necessary and this is provided for by adjustable double I bars which connect the hinge pin of the gate and the fixed anchor. The adjusting feature is accomplished by means of adjustable sleeve nut with threads of slightly different pitch and size but in the same direction. The advantage of



All Upper Gates are alike except at Lockport which is of a different type.

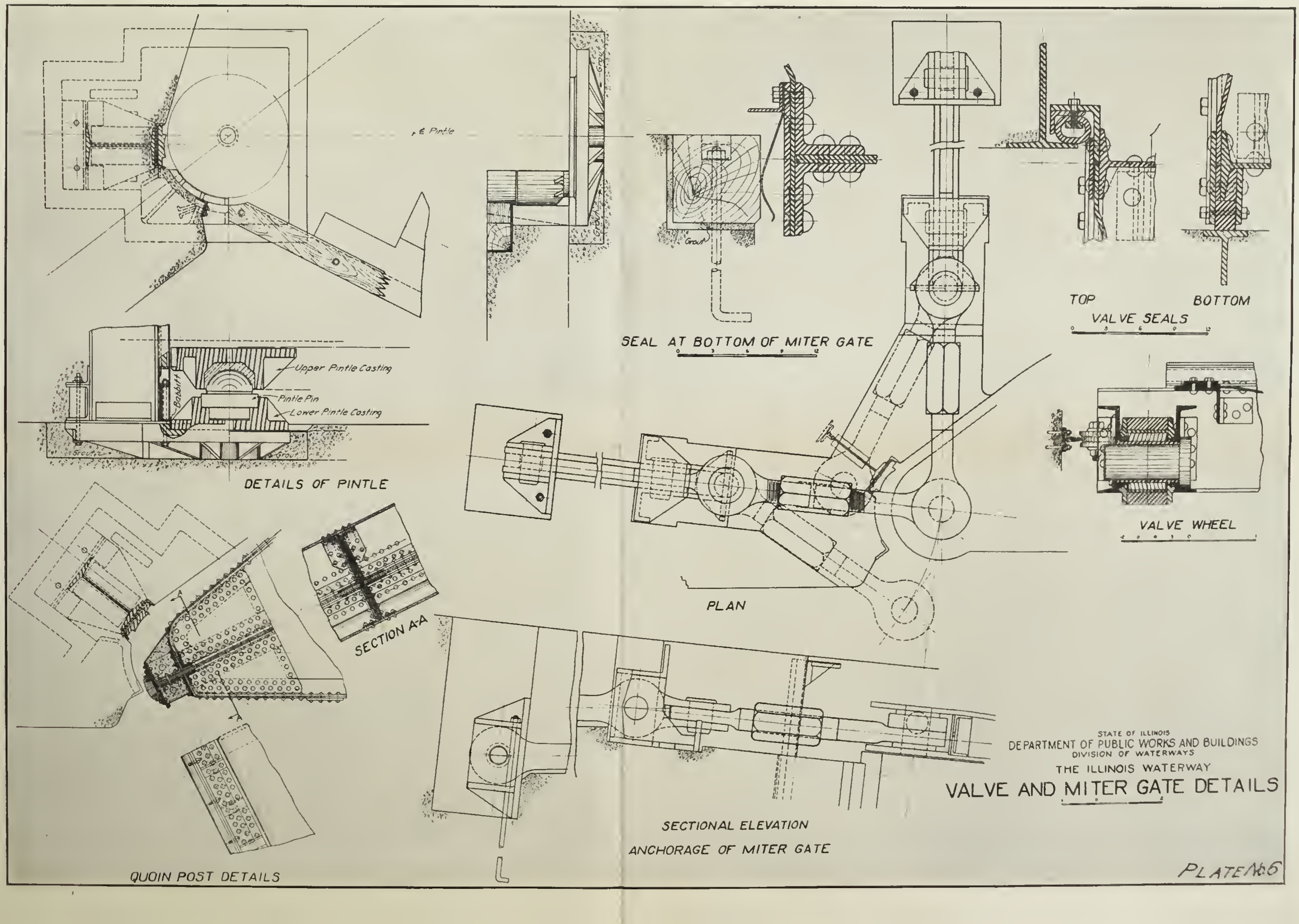
Notes The CL of all bottom girders is 2" below sill elevation
The girder coefficients (k) equal hs (head times spacing of girders) both in feet.

Drawn
Traced T.A.K. 7.13.20
Checked

STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
DIVISION OF WATERWAYS
THE ILLINOIS WATERWAY

MITER GATES
DESIGN DATA

SUBMITTED L. D. Cornish RECOMMENDED
ASST. CHIEF ENGINEER SUPT. DIV. OF WATERWAYS
APPROVED M. G. Barnes ADOPTED
CHIEF ENGINEER DIRECTOR



STATE OF ILLINOIS
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
DIVISION OF WATERWAYS
THE ILLINOIS WATERWAY

VALVE AND MITER GATE DETAILS

PLATE No. 6

this design over the ordinary turnbuckle is a much finer adjustment per turn and therefore a less force required which is an important item as adjustments must be made when the anchor is under maximum stress.

The *quoin post* which is embedded in the concrete to distribute the thrust of the gate is made up of a 24 inch Bethlehem I-beam with pressure distributing angles riveted on the back and a channel section on the front to which the hollow quoin plates are fixed. A cross section of the quoin post is shown on plate 6. The posts are in one piece and the bottom end is bolted to a projection of the pintle casting so as to facilitate the holding in exact position of the quoin post during concreting operations.

THE LOCKPORT LIFT GATE.

By F. N. Bradley, *Bridge Designer.*

At Lockport there exists a small modern lock built by the Sanitary District of Chicago to connect the Drainage Canal with the old Illinois and Michigan Canal. This lock must be retained, and the remaining available lock site is so restricted in width that, adjoining the small lock, there is not sufficient area for the mass of concrete required for the thrust of a mitering gate. Hence for these upper gates a vertical lifting horizontal truss type of gate was adopted.

Two gates similar in construction and operation will be installed. One will act as an emergency gate and will be used only in the event that it becomes necessary to remove the other for repairs.

This improvement consists of a movable gate, counterweighted, with a tower at each end, these towers being connected at the top by a service bridge placed at a clear elevation of 55 feet above the high water level.

The lock chamber is 110 feet wide, and is provided at the upper end with recesses in the side walls about five feet wide, 14 feet long and extending the full depth of the lock, and within these recesses the gate operates. The vertical travel is 23 feet 8½ inches and is accomplished in two minutes by a 50 horse power electric motor, placed at the center of the service bridge, and acting through the necessary reductions on internal gears integral with the sprocket drums. Two link chains at each end of the gate pass over these sprocket drums at the top of the towers and connect to a steel skeleton counterweight box, filled with sufficient concrete to balance the weight on the gate when immersed.

The lift gate consists of five parallel horizontal trusses, hereinafter designated as trusses Nos. 1, 2, 3, 4 and 5, and placed one below the other, truss No. 1 being uppermost. Trusses 1 and 2, also 2 and 3, are spaced 6 feet 8 inches center to center. Trusses 3 and 4, also 4 and 5, are spaced 5 feet 1 inch center to center. Each truss is of the ordinary Pratt type, with a single web system. The web members and posts are composed of angles, and the downstream or tension chord of 15 inch channels reinforced with 12 inch side plates where necessary. The upstream or compression chord is built up of four angles spaced 20 inches back to back, a 19x11/16 inch web plate, a 13 inch cover plate outside the skin plates, and reinforcing side plates where required. In addition to the direct compression, this chord was designed to carry the bending moments resulting from the uniformly applied water pressure load transferred to it from the skin plates.

Each truss is 11 feet 9 inches center to center of chords and consists of ten panels of 11 feet 9 inches each, making a distance of 117 feet 6 inches center to center of end bearings. A continuous sheet of ¼ inch buckle plates connects to the outside flange angles of the upstream chord. A set of vertical bracing, extending betwen trusses 1 and 3, is provided in the plane of the inside flange angles of the upstream chord, also in the plane of both flanges of the downstream chord, to carry the dead load stresses to the ends of the structure. Trusses 4 and 5 are suspended from this bracing by hangers at the respective panel points. The dead loads carried by this bracing are delivered to a vertical girder at each end of the gate, and thence to the two sets of link chains.

At each end of each truss, on the downstream side, there is a cast steel bearing block with a finished cylindrical bearing surface 20 inches long, bolted to the gate, which transmits the water pressure to a continuous vertical cast steel finished casting, bolted to a 24 inch Bethlehem I-beam embedded in the masonry walls.

Two guide rollers bolted to the top and bottom of the gate at each end on the upstream side, act against vertical tee guides bolted to the masonry, and limit movement in a direction parallel with the lock chamber. In a similar manner two rollers bolted to the top and bottom at each end, and placed on a line coincident with the center of gravity of the gate, limit movement in a direction at right angle with the lock chamber.

Water seals are located along the bottom and ends of the gate on the upstream side to prevent serious leakage of water when the gate is raised and the water level in the lock chamber is lowered. The bottom seal consists of a continuous line of 4½ inch standard wrought iron pipe, connected together by pipe plugs and resting on a horizontal curb angle located just below the breast wall. This pipe terminates at each end in the side of a casting, resting on but not bolted to the masonry, and the top of this casting serves as a support for the 4½ inch pipe forming the vertical seal. This vertical pipe also terminates in a casting bolted to the masonry at the upper end. Pipe plugs are provided at each end of the vertical pipe and enter recesses in the castings. These recesses allow the necessary movement for the pipe to come in contact with the gate. The horizontal pipe forms a contact between the curb angle on the masonry and the cover plate on truss No. 5. Rivets coming in contact with all pipes are countersunk. A series of T headed bolts, spaced 3 feet 6 inches center to center throughout the length of the horizontal pipe and anchored to the masonry, prevent this pipe from falling out of position when the gate is raised for repairs, and yet allow freedom of movement for it to assume a curve corresponding to the deflection of the gate under maximum pressure. The vertical seal acts in a similar manner to the horizontal, forming a contact between a vertical curb angle imbedded in the masonry and vertical plates riveted to the ends of the gate.

Owing to the great quantity of sludge in the drainage canal water a flushing system for the bottom seal and recess is necessary. A flushing pipe is placed in the breast wall masonry just back of the recess with smaller pipes leading from it into the recess at frequent intervals. This pipe is connected with a water tank placed on one of the towers of the operating bridge. Through these pipes water can be discharged into the recess under a 60 foot head.

SIDE WALL ANALYSIS.

By Walter M. Smith, *Chief Designing Engineer.*

As the culverts in the side walls of the locks are circular, the stream in the wall at the culvert cannot be found by the method used when the culvert is rectangular. It is believed in this case that the most accurate method to use in finding the stresses in the masonry around the culvert is that of "Least Work."

In this analysis the assumption is made that the arch will do the least amount of work necessary to support the load upon it. Hence if an expression can be found for the work done by each pressure line, the pressure line giving the least amount of work is the true one and the stresses in the joints can then be computed.

In the expression for work let:

W = Total work of resistance in the structure.
M = Bending moment at any assumed joint.
P = Total pressure normal to section at any assumed joint.
C = Distance from support measured along axis.
dC = An infinitesimally small distance along axis of arch.
l = Length of arch measured along axis.
E = Modulus of elasticity of material of arch.

A = Area of section at any assumed joint where P acts.
I = Moment of inertia of section of any assumed joint where P acts.
e = Distance of point of application of P from center of section at any assumed joint.

The formula for the work of resistance in an arch is:

$$W = \int_0^l \frac{M^2 dC}{2EI} + \int_0^l \frac{P^2 dC}{2EI}$$

Substituting h for the thickness of the arch at any joint and making the length of arch considered = b = one foot A = hb = h. The equation then becomes:

$$W = \int_0^l \frac{M^2 dC}{2E\,h^3/12} + \int_0^l \frac{P^2 dC}{2Eh}$$

The object now is to get a minimum value for this equation, which can only be done by trial. It is evident that all quantities that stay constant throughout the trials may be eliminated from the equations as only comparative values are wanted. 2 E is therefore dropped from the equation and for M its value Pe is substituted, making the equation:

$$W = \int_0^l \frac{P^2 e^2 dC}{h^3/12} + \int_0^l \frac{P^2 dC}{h}$$

This is the form in which the equation is used except that the assumption that the arch may be divided up into a number of joints so that dC the distance between assumed joints, is constant, we may use the summation instead of the actual integral without appreciable error in the comparative value computations. The equation in its final form is:

$$W = \sum \frac{P^2 e^2}{h^3/12} + \sum \frac{P^2}{h}$$

h, P and e being obtained for each joint in turn, substituted in the equation and the sum then taken for all the joints.

After the arch has been divided up and the forces acting on the various blocks found, a force polygon can be drawn and the resultants obtained from it in direction and magnitude. The point of application of each resultant can then be found by taking the sum of the moments of all the forces acting on one-half the arch about any point and dividing this moment by the resultant. This will give the lever arm of the resultant about the center of moments and the resultant can then be drawn in position on the arch.

There are three unknown quantities that have to be obtained, the horizontal and vertical components and the point of application of the crown thrust and all are obtained very easily by this process.

Any point on the spring line and crown joint may be taken and the horizontal crown thrust obtained that will pass a pressure line through the point on the crown joint and the spring line, by taking moments of all the forces acting on that half of the arch about the point on the spring line and dividing the sum by the distance to the line of action of the crown thrust. This thrust can then be used applied at various points on the crown joint, the pressure line drawn and the work computed for each.

It is generally desirable to apply the thrust at about five points on the crown joint at equal distances apart then it is only necessary to draw the two other pressure lines as the distance apart of these lines can be measured at each joint and divided by four in getting the values of e for each line.

After the work has been obtained for the set of pressure lines for this crown thrust assume a thrust a little larger or smaller, pass pressure lines through the same points on the crown joint as before and through others if necessary to pass through a minimum and compute as before.

After computations have been made for five or six different crown thrusts the value of the work for each thrust at each different point of application should be plotted on a cross section diagram with the work as ordinates and the point of application at the crown as abscissae. By connecting the points thus plotted for the same crown thrust in each case, a series of curves is obtained. Next draw a curve passing through the lowest point on each of these curves. The lowest point on this curve gives the point of application of the true crown thrust. Next on another crosssection diagram with work as ordinates and horizontal component of crown thrust as abscissae plot the lowest point on the curve for each of the trial horizontal components of the crown thrust. Draw a curve through these points. The lowest point will give the true horizontal component of the crown thrust. This leaves only the true vertical component of the crown thrust to be obtained. As the true horizontal component and point of application of the crown thrust are now known try several different vertical components using the same horizontal component and point of application in each case. Of course, for each vertical component it is only necessary to draw one pressure line as the point of application is already known. When a sufficient number of different vertical components have been tried to obtain a minimum the results are plotted on a cross section diagram as before with the work as ordinates and the vertical components as abscissae. Passing a curve through these points and taking the lowest point on the curve the true vertical component is obtained.

Having the true vertical and horizontal components and point of application the true pressure line may be drawn and stresses in the various joints computed.

A cross section of the Marseilles lock wall is shown on Plate 7.

The wall will be built up to the level of the shoulder then a wait will occur until the concrete sets sufficiently to erect the forms for the back of the wall upon it. There will therefore be a well defined joint on this line. The wall above this line is designed so that for the most adverse conditions possible there will be no tension at the heel. The stress diagram for this joint is then drawn as shown and the upper wall supposed to be replaced by this pressure on the top of the arch. The arch is then divided into sections by imaginary joints and the forces found acting on each of these blocks. A force diagram is then drawn and the resultants acting on the two halves obtained in direction, magnitude and point of application as already explained. Having the moments of all the forces on each half of the arch already it is very easy to obtain the horizontal component of crown thrust to pass a pressure line through any point on the spring line. It will be noticed from Plate 8 that the trial crown thrusts used are not horizontal, but very much inclined. It is not necessary to use a horizontal crown thrust but in the first set of computations to find the true horizontal component and point of application the vertical component must be the same for each trial.

Computation Table

1 Joint	2 h	3 $\frac{h^3}{12}$	4 $\frac{P}{1000}$	5 $\left(\frac{P}{1000}\right)^2$	6 $\frac{\left(\frac{P}{1000}\right)^2}{\frac{h^3}{12}}$	7 $\frac{\left(\frac{P}{1000}\right)^2}{h}$	8 e_{-2}	9 e_{-2}^2	10 Col.6 × Col.9	11 e_{-1}	12 e_{-1}^2	13 Col.6 × Col.12	14 e_0	15 e_0^2	16 Col.6 × Col.15	17 e_1	18 e_1^2	19 Col.6 × Col.18	20 e_2	21 e_2^2	22 Col.6 × Col 21
1	10.0	83.3	38.1	1452	17.5	145.2	1.70	289	50.5	1.38	1.90	33.2	1.07	1.14	11.9	0.75	0.56	9.8	0.43	0.19	3.2
2	10.0	83.3	36.6	1340	16.1	134.0	1.22	1.49	24.0	0.89	0.70	11.3	0.55	0.30	4.9	0.22	0.05	0.8	0.12	0.10	0.2
3	7.5	35.2	33.6	1129	32.1	150.6	1.52	2.31	74.3	1.15	1.32	42.4	0.78	0.61	19.5	0.41	0.17	5.4	0.04	0.00	0.0
4	5.6	14.6	32.3	1043	71.3	186.5	1.67	279	199.0	1.30	1.69	120.4	0.93	0.87	61.7	0.56	0.31	22.4	0.19	0.04	2.6
5	4.4	6.9	30.7	942	137.5	216.5	1.77	3.13	430.0	1.37	1.88	258.0	0.97	0.94	129.4	0.58	0.34	46.2	0.18	0.03	4.4
6	4.0	5.3	29.6	876	164.5	219.0	1.63	2.66	438.0	1.23	1.51	249.0	0.83	0.69	113.3	0.43	0.19	30.5	0.03	0.00	0.2
7	4.4	6.9	27.7	767	112.0	176.3	1.50	2.25	270.0	1.07	1.14	137.0	0.64	0.41	49.2	0.21	0.04	5.3	0.22	0.05	5.8
8	5.5	13.9	25.8	666	481	121.0	1.41	199	95.7	0.94	0.88	42.3	0.47	0.22	10.6	0.00	0.00	0.0	0.47	0.22	10.6
9	8.1	44.3	24.6	605	13.6	74.8	1.49	2.22	31.0	0.99	0.98	13.3	0.49	0.24	3.3	0.00	0.00	0.0	0.50	0.25	3.4
10	5.6	14.2	13.6	185	13.0	33.7	1.84	3.39	44.1	096	0.92	12.0	0.08	0.01	0.1	0.80	0.64	8.3	1.68	2.82	36.7
11	44	69	11.1	123	180	28.3	2.10	4.41	79.5	1.02	1.04	18.8	0.06	0.00	0.1	1.14	1.30	23.4	2.22	4.93	88.8
12	4.0	5.3	120	144	27.1	36.0	2.00	4.00	108.4	1.00	1.00	27.1	0.00	0.00	0.0	1.00	1.00	27.1	2.00	4.00	108.4
13	4.4	6.9	16.2	262	38.3	60.3	1.92	3.69	141.5	1.18	1.39	53.3	0.44	0.19	7.4	0.30	0.09	3.5	1.04	108	41.4
14	5.6	14.2	26.1	681	47.9	122.6	1.75	3.06	146.5	1.30	1.69	81.0	0.85	0.72	34.6	0.40	0.16	7.7	0.85	0.72	34.6
15	8.2	45.9	487	2372	51.8	289.0	1.41	1.99	103.0	1.17	1.37	71.0	0.93	0.87	44.8	0.69	0.48	24.6	0.45	0.20	10.6
16	9.0	60.7	726	5271	86.8	585.0	0.68	0.46	40.1	1.52	0.27	23.4	0.36	0.13	11.3	0.20	0.04	3.5	0.04	0.00	0.2
17	7.5	34.4	75.8	5746	1670	772.0	0.05	0.00	0.5	1.23	0.05	89	0.41	0.17	28.1	0.59	0.39	58.1	0.77	0.59	97.4
18	71	28.6	73.3	5373	1876	762.5	0.90	0.81	152.0	1.07	1.14	214.0	1.24	1.54	2890	1.41	1.99	374.0	1.58	2.50	469.0
19	84	33.8	75.5	5700	1686	6830	1.28	1.64	276.5	1.43	2.04	344.0	1.58	2.50	4210	1.73	299	504.0	1.88	3.53	595.0
20	10.6	72.6	779	6068	83.6	575.0	2.06	424	354.0	1.22	4.93	412.0	238	5.66	4730	2.54	645	539.0	2.70	723	609.0
21	14.5	2540	80.6	6496	25.5	448.0	2.66	7.07	180.0	281	7.90	202.0	296	8.76	223.5	3.12	9.73	248.2	3.28	1076	274.0
22	17.0	410.0	85.7	7344	17.9	432.0	4.28	18.32	328.0	4.43	1962	352.0	4.58	2098	376.0	4.73	22.37	400.0	4.88	23.81	427.0
23	17.0	410.0	88.3	7797	19.0	459.0	4.49	20.16	384.0	463	2144	408.0	477	2275	433.0	4.91	24.11	459.0	5.05	25.5	486.0
						6710.8			3950.6			3134.4			2745.7			2800.8			3308.5
									6710.8			6710.8			6710.8			6710.8			6710.8
									10661.4			9845			9456.5			9511.6			10019.3

On Plate 8 is shown a trial computation for a horizontal component of 12,000 and the computation table is shown. In drawing the pressure lines on the arch it is well to first prolong the crown thrusts at the extremes out to the resultants and then draw lines from their intersections on the resultants, parallel with the line in the force diagram representing the resultant of the crown thrust and all the forces on one half of the arch. These lines are A 1 and A 23 in the force diagram. This will give points on the spring line to which the pressure lines drawn from joint to joint must come if correct. Only the two outside pressure lines are drawn on Plate 8 although there are five used in the computation. The intermediate values of e can be very easily obtained as they are all an equal distance apart. P is the same on each joint for all the lines. It will be noticed that the value of P is divided by 1,000. This is done to not have too large numbers in the computations and does not affect the comparative results.

After completion of this computation another value of crown thrust is taken and a similar table computed for it. Four different values of crown thrust were used in this case, the horizontal components being 13,000, 12,000, 11,000 and 9,000. The values of work for each of these crown thrusts for each point of application were then plotted on the cross section shown in Fig. 3, Plate 10 and a curve connecting the points for each crown thrust was drawn. A curve was then drawn through the lowest point on each of these curves and thus a value of 1.4 feet above the center obtained for the point of application for the true crown thrust. The lowest point of each of the curves for different crown thrusts were then plotted on Fig. 2, Plate 10 and a value of 10,000 obtained for the horizontal component of the true crown thrust.

Using this horizontal component of crown thrust and point of application, three computations were made assuming vertical components 2,000, 3,000 and 5,000. As before stated the table for this computation is the same as for obtaining the horizontal component except that for each vertical component assumed only one pressure line is drawn as the point of application is known.

The values obtained for the different vertical components are then plotted on the cross section diagram Fig. 1, Plate 10 and a curve drawn through these points. The lowest point on this curve gives a value of 3,700 as the true vertical component.

Having now obtained the true vertical and horizontal components and point of application of the crown thrust it is a very simple matter to draw the true pressure line and compute the stresses in the various joints. The pressure line and stresses obtained for the section in question are shown on Plate 9.

It is not claimed that this method will give exact results but it is believed to give results nearer the truth in a case of this kind than any other method. The computation would be rigidly true if the arch is divided up so that $\frac{dc}{I}$ is constant for the first term of the formula and performing this part of the computation then divide it up so that $\frac{dc}{a}$ is constant and use this division for the second term of the formula.

In designing the arched conduits through the dams for the Miami Conservancy District at Dayton, Ohio, this was done for one of the arches as a check after the true pressure line had been obtained by the method described above. It was found that the pressure lines obtained by the two methods were practically identical the crown thrust only differing one-sixth of one per cent and the point of application coming out practically the same.

FEDERAL WATER POWER PERMIT.

One achievement of the Division of Waterways during the year was to secure approval of plans and the permit of the Federal Power Commission for water power development in connection with construction of the Illinois Waterway.

This permit was formally issued by the Federal Commission January 14, 1922, and the State of Illinois is thus protected in the acquirement and development of all water power incidental to the construction of the waterway. From this water power there will be a large revenue to the State; also the opportunity of great industrial locations with increased population and larger corporation revenues to the State.

ILLINOIS AND MICHIGAN CANAL.

Floods in the spring of 1922 resulted in more or less damage to the Illinois and Michigan Canal and delayed opening of the canal for navigation.

During the year repairs to permanent structures have been made so that the canal is now in first class condition for such navigation as it will afford. It will be of service to the State in transporting material for construction work on the more adequate waterway for improvement of the Illinois and DesPlaines Rivers.

There was increase in expense for maintenance of the canal because flood damage resulted in heavy fills in channels of the canal at a number of places and the washing out of banks.

Several leases have been executed establishing the right of the State in disputed territory to the right of way of the canal.

Numerous encroachments have been prevented.

The expenditures for the year July 1, 1921, to June 30, 1922, were..	$33,249.62
Receipts for the same period..	31,666.80
Available balance on hand in the Canal Fund July 1, 1922..........	25,282.74

ILLINOIS RIVER WORK.

During the year, dredging has been necessary for navigation on the Illinois River at Henry and Copperas Creek Locks and at LaSalle.

STREAM GAGING.

Determination of the flow of important streams was continued, in cooperation with the U. S. Geological Survey; twenty-seven gaging stations were maintained during the year. Stream flow records are essential to the proper study of drainage and flood control problems and of water power development and are of value in matters of sanitation and water supply. Records for 1903, 1904 and 1908 to 1911 are published in a report of the Rivers and Lakes Commission, since 1911 are published annually in Water Supply Papers of the Geological Survey.

This year's records are of particular interest as showing stages and volume of the excessive spring floods. The observations made on the Illinois River during this and previous floods are the basis of special report which is found herein. Previous high water records were exceeded this year also on the Kankakee, Embarass and Kaskaskia Rivers and on several smaller streams.

SURVEYS AND INVESTIGATIONS.

As the result of flood conditions throughout the State in March and April, 1922, the Division of Waterways made investigations as to the cause and effect thereof and has prepared an exhaustive report thereon. These investigations required that engineers visit cities upon the Illinois, Mississippi, Ohio, Wabash, Embararrass, Cache, Sangamon and Pecatonica Rivers. Much valuable data was obtained of benefit to the people of the State available in the report issued.

Complaints of encroachments at various points throughout the State reaching the Division of Waterways required surveys to determine public interests. The data obtained has been filed and will be available in future to the people of the localities affected.

During the year 285 permits have been issued, requiring submission to the division, engineering check and approval of plans, for construction for shore line protection, dredging, marine cables, bridges, breakwater piers, dams, docks, boat piers, sewage disposal plants where outlets discharge into streams, and drainage districts. This involves a great amount of work but under the provisions of the statutes of the State requiring the division to handle this work, public interests are adequately protected and abuses so common heretofore have been prevented.

ENCROACHMENTS AND POLLUTION.

Encroachments upon rivers and lakes in the State have resulted in numerous complaints to the Division of Waterways during the year and constant patrol of the more important streams of the State has been found necessary to protect public rights affecting navigation and the proper and lawful discharge of flood waters through these streams. Hundreds of such complaints have been received in connection with Lake Michigan, the Chicago River and its branches, Calumet River and from numerous points throughout the State. All of these complaints have been given very careful investigation and consideration and in most instances satisfactory adjudication reached. In two or three cases suits may be necessary to enforce provisions of law applicable. For a number of years there was no statute giving any State supervision over encroachments upon streams. Because of this lack of State control abuses have resulted which are entirely responsible, on some streams, and largely responsible on other streams, for the damage experienced last spring from floods.

Complaints of encroachments have necessitated inspections by engineers of the division at a number of points on the Fox River, Fox Lake and other lakes of the Fox River system, the Illinois River, Chicago River and its branches, Lake Michigan, and the Mississippi River, Little Wabash and others.

Effort has been made to prevent pollution of streams throughout the State. This is a difficult problem. Pollution of the DesPlaines and

Illinois Rivers is attributable largely to the present system of sewage disposal by the Sanitary District of Chicago. Conditions of pollution of the Illinois River are more pronounced now than ever before and this condition must continue until such time as the Sanitary District of Chicago puts in operation some system of sewage disposal other than dilution by water. The work in this connection is not progressing as rapidly as public interests require.

Polluted conditions of the DesPlaines River within Cook County are extremely bad. Under an Act of the Fifty-second General Assembly municipalities discharging sewage into the DesPlaines River have been annexed to the Sanitary District of Chicago.

The flow of water in the DesPlaines River during the low water period of the summer months is totally inadequate to handle the sewage load discharged therein and conditions are of such character as result in a public nuisance. Sewage treatment by these municipalities or by the Sanitary District, of which they are now a part, is imperative and should be provided without delay.

The Division of Waterways has successfully coped with and adjusted conditions of pollution complained of affecting the Vermilion River at Hoopeston. The river was badly polluted by the discharge of wastes from the Illinois Canning Company and the Hoopeston Canning Company. The conditions have been a subject of investigation for the last four or five years. The companies finally agreed with the Division of Waterways to clear up the situation. This has been accomplished by the installation of adequate treatment plants for the waste products. A similar situation at Rochelle, resulting in numerous complaints of gross pollution of Kyte Creek by the discharge of canning and gas house wastes therein, has been adjudicated by the installation of proper treatment sedimentation and filtration plants.

At Pontiac a treatment plant had been installed by the city authorities. Construction was unsatifcatory and resulted in inefficient operation. The State was interested in proper disposal of sewage in connection with the Reformatory located there. State appropriations were not paid because of the faulty condition of the construction under contract by the city. Owing to the State's interest in the situation the Division of Waterways was called upon to design proper treatment plant for this location. The City of Pontiac purchased a new site. Engineers of this division supervised the construction. The plant is completed and efficiently operated.

Long standing complaints of the pollution of Thorn Creek in the vicinity of Chicago Heights have been partially adjusted during the past year by installation in that city of treatment plants to handle the sanitary sewage, these comprising Imhoff tanks and sprinkling filters. The pollution of this stream is not fully overcome because considerable industrial wastes enter the stream that are not cared for by the city plant. The situation is still under investigation in connection with the disposal of industrial wastes, the division being hopeful of finding some solution to this problem during the coming year.

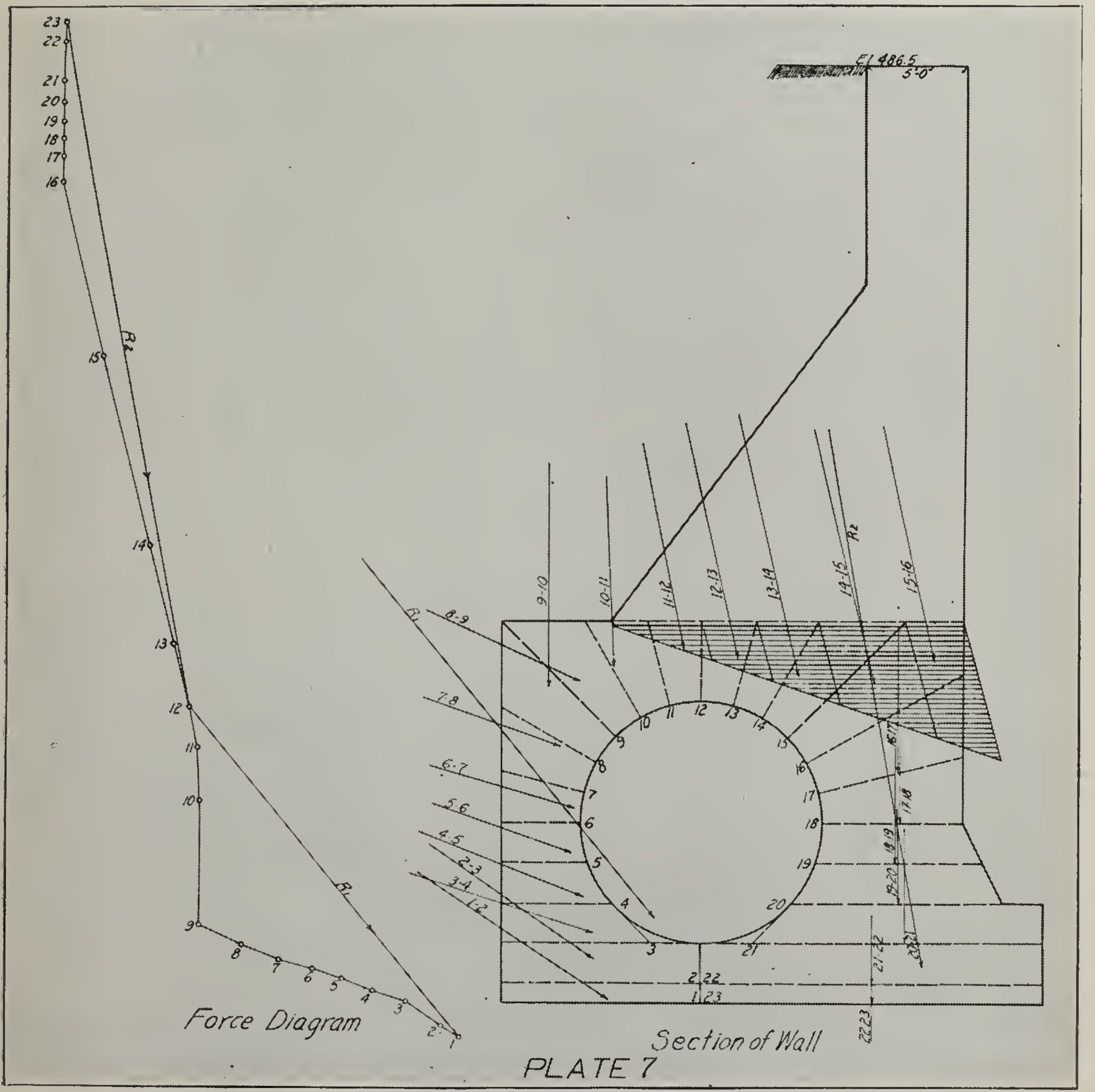
In the spring of 1922 many complaints were received from people of communities on or near the Fox River, complaining of pollution that resulted in killing most of the fish in the stream below Aurora. Investigation of these conditions engaged the attention of the engineers and other officers of the division several weeks. It was found fish had been killed as the result of a discharge of the gas house wastes into the stream from the gas plant of the Western Gas and Electric Company at Aurora. Changes in conditions at the plant of this company have been made by order of the Division of Waterways and it is believed there is no opportunity of the gas house waste again polluting the river to an extent that will affect fish life. It is certain no such condition will result unless the company deliberately discharges from banks of the stream waste material from its plant instead of caring for it as directed by the Division of Waterways and other State agencies interested in fish propagation.

Sewage disposal conditions at Downers Grove have been bad for a long period of time. As a result of the cooperation of the Division of Waterways that municipality is having a sewage treatment plant installed which it is anticipated will do away with the gross pollution of Bishop Creek which has resulted in numerous complaints in the past.

Effort is being made by officers of the city of Wheaton to install plant for sewage treatment to overcome numerous complaints of pollution which results in a public nuisance. Opposition and some litigation is delaying the work to some extent but upon the complaint of the Division of Waterways the Attorney General has filed in the Circuit Court a bill against the officers of the city to abate the nuisance which results from existing conditions. It is hoped such progress may be made in this connection as to enable actual work being started at an early date.

Polluted conditions of the Fox River from Elgin to Aurora have been investigated as the result of complaints. Elgin has twelve sewers emptying into the river, Aurora has nine, and there are sewer outlets from various private and manufacturing plants along the river, all without treatment plants. After an effort covering a period of years by the Division of Waterways, the city of Elgin is proceeding with the organization of a Sanitary District, as the result of which the situation in that city may be cleared up and proper sanitation treatment obtained. It will be necessary that existing conditious at Aurora be given early consideration and sewage discharge from manufacturing plants and others curtailed.

Geneva, Batavia, St. Charles and the three State institutions at Elgin, St. Charles and Geneva have sewage treatment plants in operation which are in fair condition.


Force Diagram
Section of Wall
El. 486.5
5'-0"
R₂
R₁
9-10
10-11
11-12
12-13
13-14
14-15
15-16
8-9
7-8
6-7
5-6
4-5
2-3
3-4
1-2
16-17
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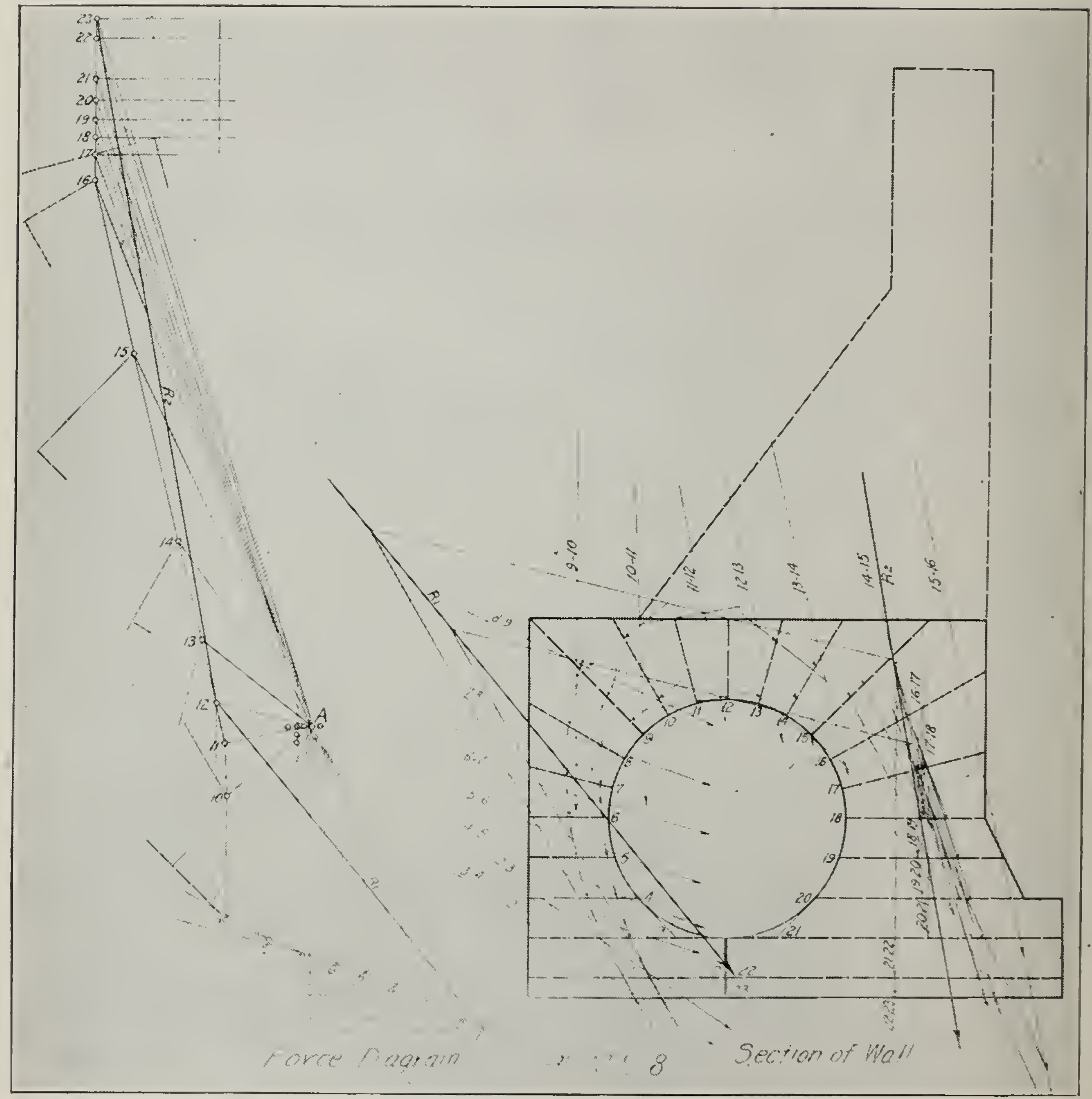
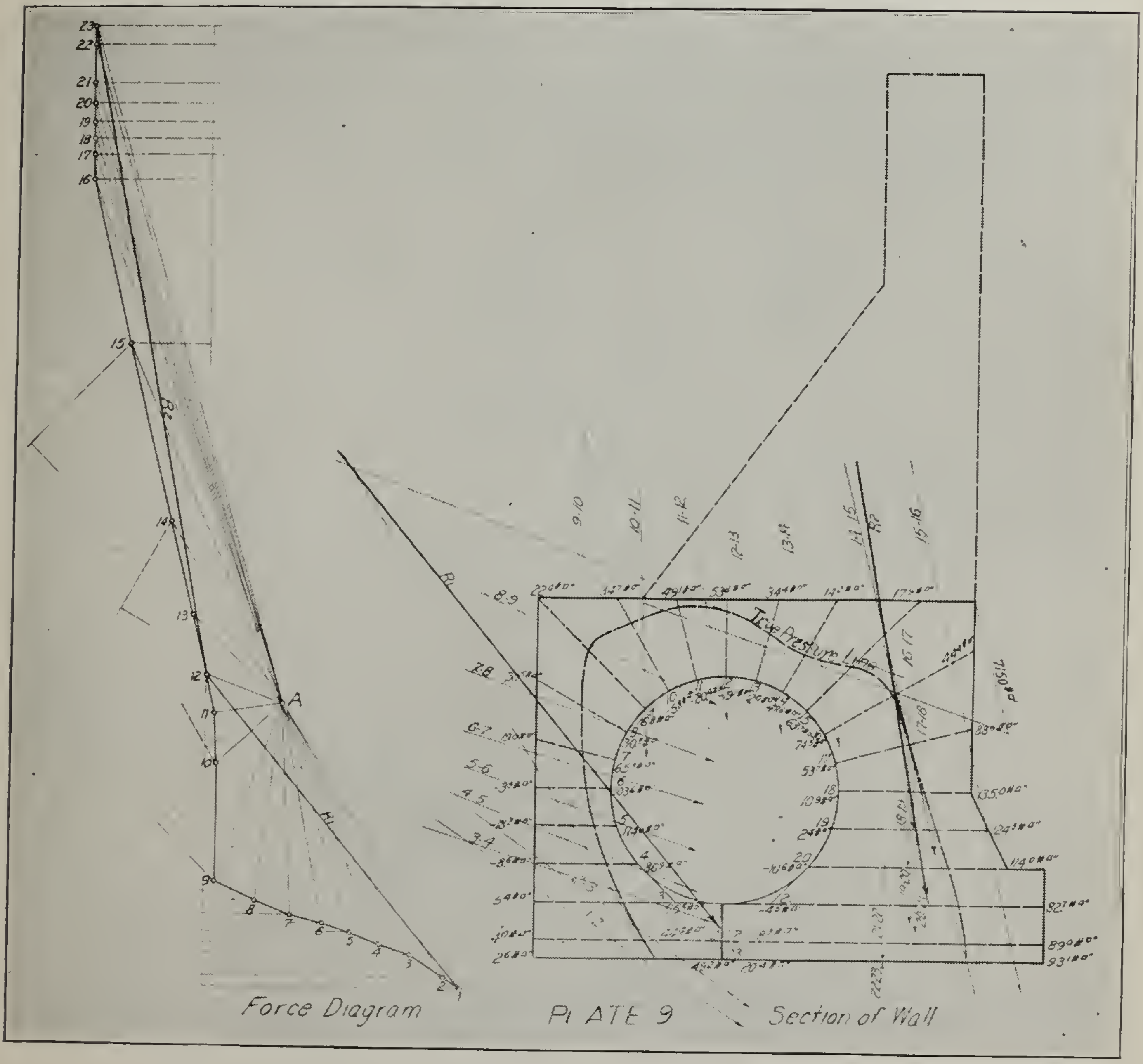
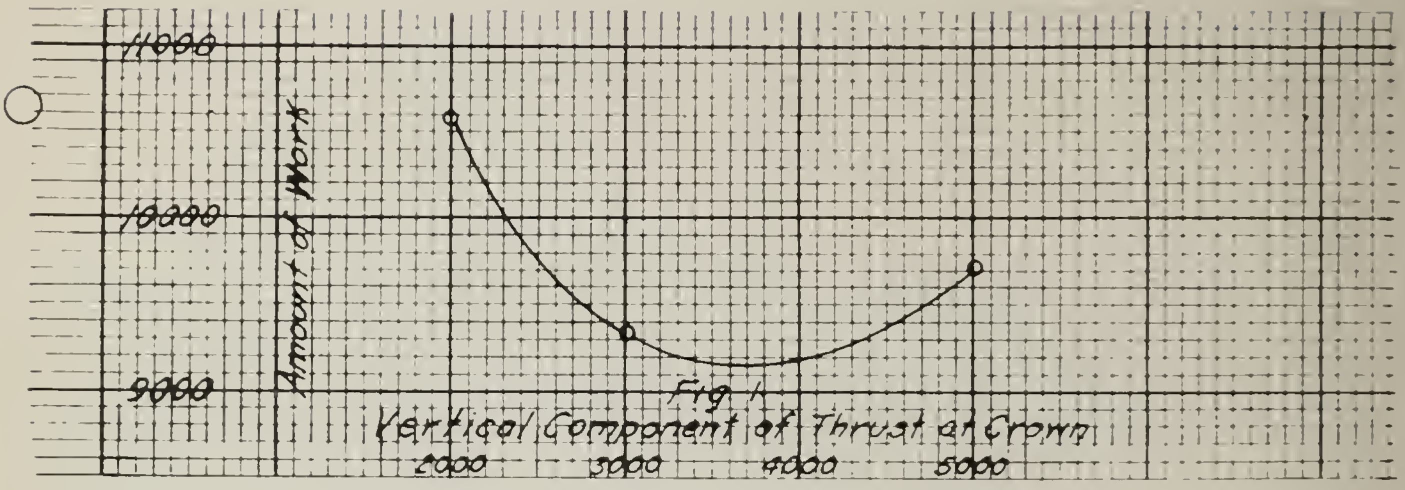
2-22
1-23

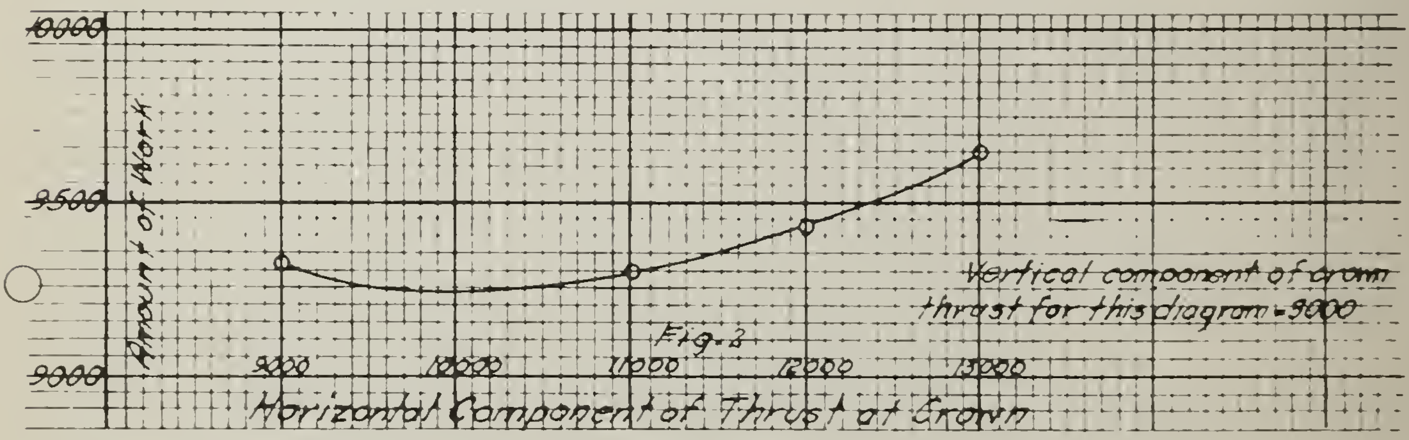
PLATE 7


Force Diagram
8
Section of Wall
A
R1
R2
9-10
10-11
11-12
12-13
13-14
14-15
15-16
16-17
17-18
18-19
19-20
20-21
21-22



Force Diagram PLATE 9 Section of Wall





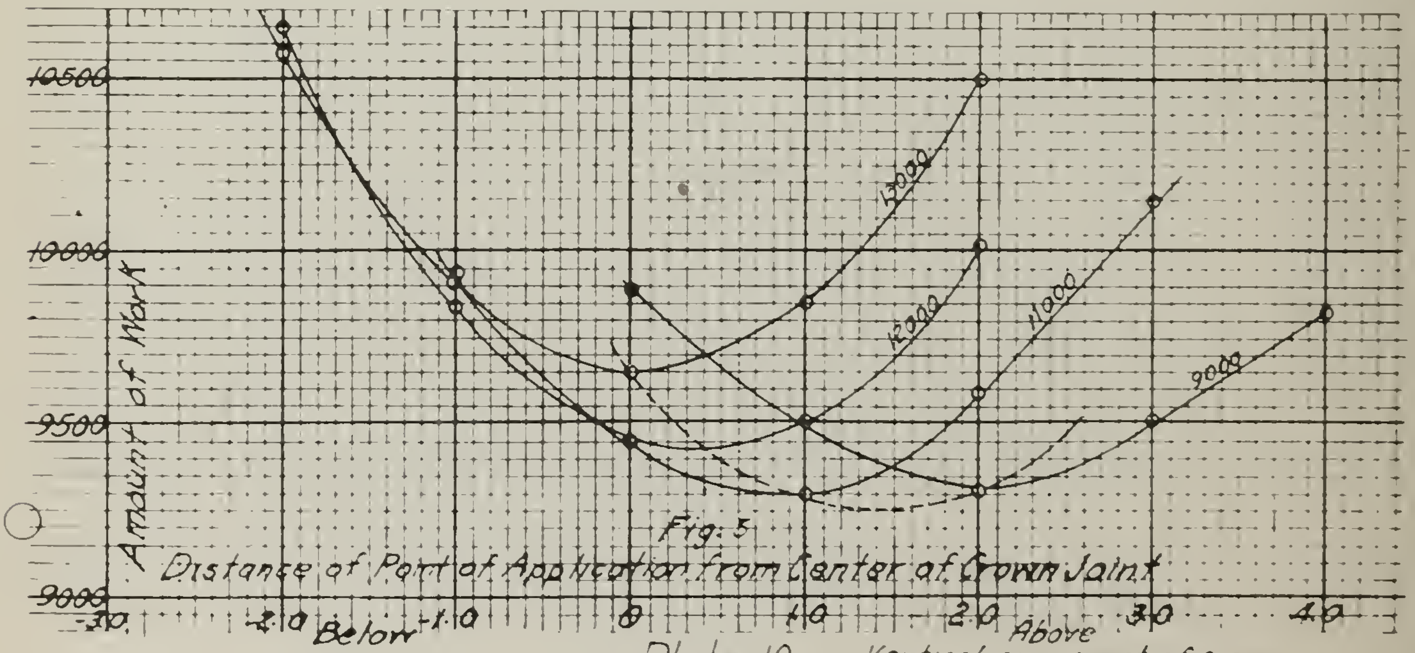


Plate 10

Vertical component of crown thrust for this diagram = 3000

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